LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN
Department "Institut für Informatik"
Lehr- und Forschungseinheit Medieninformatik
Prof. Dr. Heinrich Hußmann

Diploma Thesis

Design and Distribution of Physical and Mobile Interfaces for Multi-Tag Interaction

Doris Hausen
hausen@cip.ifi.lmu.de

Bearbeitungszeitraum: 01. 01. 2009 bis 30. 06. 2009
Betreuer: Dipl.-Medieninf. Gregor Broll
Verantw. Hochschullehrer: Prof. Dr. Heinrich Hußmann

Zusammenfassung

Physical Mobile Interaction beschreibt die Interaktion zwischen einem mobilen Endgerät und einem physikalischen Objekt. Bluetooth, numerische Identifikatoren, visuelle Codes oder auch Near Field Communication (NFC) sind technische Voraussetzungen dafür. Bis heute, wie auch im Abschnitt zur Related Work dargestellt, basieren die meisten Anwendungen auf diesem Gebiet auf Single-Tag Interaction, also der Interaktion mit einem einzigen Tag, das meist zum Starten der Anwendung oder eines Dienstes verwendet wird. Einige wenige Ansätze überwinden diese Begrenzung und verwenden, beziehungsweise kombinieren, mehrere Tags. Diese Art der Interaktion nennt sich Multi-Tag Interaction. Neben einigen konkreten Beispielen wird vor allem ein genereller Überblick gegeben, der eine Kategorisierung verschiedener Multi-Tag Ansätze beinhaltet. Die vier Kategorien lauten wie folgt: Navigation, Selektion, Kombination von Information und Abbildung. Während der Durchführung von drei Nutzerstudien wurden drei dieser Kategorien (Navigation, Selektion und Kombination von Information) in Bezug auf allgemeine Bedienbarkeit und der Verteilung von Information zwischen dem mobilen Endgerät und dem physikalischen Interface evaluiert. Mit Hilfe verschiedener Prototypen, die alle aus einer Java ME Anwendung mit NFC Unterstützung und einem Poster mit Tags bestanden, wurden quantitative Daten, wie die Ausführungszeit, Aufmerksamkeitswechsel und Fehler, sowie auch qualitative Daten, basierend auf den Rückmeldungen der Benutzer, gesammelt.

Abstract

Physical mobile interaction is the interaction between a mobile device and a physical object. Using enabling technologies like bluetooth, numeric identifiers, visual codes or near-field communication (NFC), this kind of interaction is made possible. Up to now, as depicted in the related work section, the focus in this area is based on single-tag interaction meaning only one single tag is used in an application, usually to start an application or a service. Consequently only very few approaches rise above this and use, reuse and combine more than one tag. This interaction style is called multi-tag interaction. Aside from concrete examples, a general categorisation for multi-tag interaction is given stating four categories: Navigation, Selection, Combination of Information and Mapping. Conducting three user studies, three of these categories (Navigation, Selection and Combination of Information) are evaluated considering their general usability and the distribution of information on the mobile interface as well as the physical interface. Using different prototypes, consisting of a Java ME based mobile application supporting NFC and a tag-enhanced poster, quantitative data, like execution time, attention shifts and errors, is collected as well as qualitative data based on user feedback.

Task Definition:

Design and Distribution of Physical and Mobile Interfaces for Multi-Tag Interaction

Background: The advancement of Ubicomp technologies such as NFC or visual markers has increased the possibilities for mobile interaction with tagged objects from the real world as well as associated information and services. Due to the increasing technical advancement and distribution of tagging technology, this Physical Mobile Interaction evolves towards Multi-Tag Interaction that uses mobile devices to interact with multiple objects, tags and information. As a result of this development, physical objects can act as physical interfaces with multi-tags that complement mobile interfaces and adopt some of their features.

General Objectives: The goal of this thesis is to investigate the interface and interaction design of multi-tag applications focusing on its distribution between tagged physical objects and mobile devices. For that purpose, this thesis will explore different examples for multi-tag applications, analyse common workflows, patterns or designs and derive general properties of Multi-Tag Interaction that influence the design of its applications. Based on this analysis, this thesis will develop and evaluate different prototype applications according to common workflows and designs for Multi-Tag Interaction. Each prototype will comprise different designs for the same application or workflow in order to evaluate the properties of multi-tag interfaces that are distributed between physical and mobile interfaces.

Tasks: This diploma thesis includes the following tasks:

- Surveying related work about Physical Mobile Interaction, especially Multi-Tag Interaction, with a focus on tagged, physical interfaces
- Overview and analysis of multi-tag applications regarding common interaction designs, patterns or workflows as well as properties of mobile and physical interfaces that determine them (e.g. distribution of interfaces, different physical interfaces...)
- Categorisation and definition of common multi-tag interactions and applications
- Design and development of different prototypes for common Multi-Tag Interactions focusing on the distribution of their interfaces between physical and mobile interfaces
- Comparison and evaluation of different designs for these prototypes
- Written diploma thesis in English
- Reporting on progress in intermediate and final presentation

Ich erkläre hiermit, dass ich die vorliegende Arbeit selbstständig angefertigt, alle Zitate als solche kenntlich gemacht sowie alle benutzten Quellen und Hilfsmittel angegeben habe.

München, June 25, 2009

. . . .

Contents

1 Introduction **1**

2 Related Work **3**
2.1 Enabling Technologies 3
2.1.1 Numeric Identifier 3
2.1.2 Bluetooth 3
2.1.3 Infrared 3
2.1.4 Location-based 4
2.1.5 Visual Markers 4
2.1.6 Near Field Communication 4
2.2 Interaction Techniques 5
2.2.1 Basic Physical Mobile Interaction Techniques 5
2.2.2 Advanced Physical Mobile Interaction Techniques 8
2.3 Classification of Physical Mobile Applications 13
2.3.1 Presentation of Information 13
2.3.2 Physical Hyperlinks 13
2.3.3 Tagging 14
2.3.4 Broadcasting 14
2.3.5 Tag Emulation 14
2.3.6 2-Way Interaction 14
2.4 Usability Requirements 15

3 Analysis **17**
3.1 Navigation 17
3.2 Selection 18
3.3 Combination of Information 19
3.4 Mapping 20

4 1st User Study: Navigation and Selection **21**
4.1 Basic Use Case 21
4.1.1 Single-Tag Interaction 22
4.1.2 Multi-Tag Interaction #1 23
4.1.3 Multi-Tag Interaction #2 25
4.1.4 Multi-Tag Interaction #3 27
4.2 Implementation 27
4.2.1 The Mobile Application 27
4.2.2 The NFC-Enhanced Poster 31
4.3 User Study Design 32
4.3.1 Experimental Design 32
4.3.2 Conducting the User Study 36
4.4 Evaluation of the User Study 37
4.4.1 Demographics and Technical Background 37
4.4.2 Attention Shifts 37
4.4.3 Errors 39
4.4.4 Execution Time 41
4.4.5 Verifying the Hypotheses 45
4.4.6 User Feedback 46

5 2nd User Study: Actions and Objects 55
5.1 Basic Use Case . . . 55
5.1.1 Single-Tag Interaction . . . 56
5.1.2 Multi-Tag Interaction #1 . . . 58
5.1.3 Multi-Tag Interaction #2 . . . 59
5.1.4 Multi-Tag Interaction #3 . . . 61
5.1.5 Multi-Tag Interaction #4 . . . 61
5.2 Implementation . . . 63
5.2.1 The Mobile Application . . . 63
5.2.2 The NFC-Enhanced Poster . . . 63
5.3 User Study Design . . . 63
5.3.1 Experimental Design . . . 64
5.3.2 Conducting the User Study . . . 67
5.4 Evaluation of the User Study . . . 67
5.4.1 Demographics and Technical Background . . . 68
5.4.2 Attention Shifts . . . 68
5.4.3 Errors . . . 70
5.4.4 Execution Time . . . 71
5.4.5 Verifying the Hypotheses . . . 74
5.4.6 User Feedback . . . 76

6 3rd User Study: GUI Widgets 83
6.1 Basic Use Case . . . 83
6.1.1 Single-Tag Interaction . . . 83
6.1.2 Multi-Tag Interaction #1 . . . 85
6.1.3 Multi-Tag Interaction #2 . . . 85
6.2 Implementation . . . 88
6.2.1 The Mobile Application . . . 88
6.2.2 The NFC-Enhanced Poster . . . 89
6.3 User Study Design . . . 89
6.3.1 Experimental Design . . . 89
6.3.2 Conducting the User Study . . . 91
6.4 Evaluation of the User Study . . . 92
6.4.1 Demographics and Technical Background . . . 92
6.4.2 Attention Shifts . . . 92
6.4.3 Errors . . . 92
6.4.4 Execution Time . . . 94
6.4.5 Verifying the Hypotheses . . . 97
6.4.6 User Feedback . . . 97

7 Conclusion 103

1 Introduction

Physical mobile interaction is the interaction between a mobile device and the physical environment. Expanding conventional interaction with mobile devices and using physical mobile interaction facilitates a simpler and more intuitive attendance. At the moment the user is accustomed to navigate through long menus and search through a long list of items on the display of his mobile device. Adapting to physical mobile interaction, the user can simply point his mobile device at a physical object and touch it and by means of that interact with it [5].

Using physical mobile interaction offers a broad range of interaction styles to the user and moreover limited visual output capabilities of mobile devices, like the small display, as well as limited input capabilities, like the rather small keypad, are overcome. Even more, those characteristics of mobile devices can be combined and therefore fulfill new and useful functions e.g. serve as additional private screen for personal data [14].

Up to now, many applications only use physical mobile interaction to offer a shortcut to an application, hence only the first interaction step is realized using technologies like visual markers or near field communication. Further interaction is carried out using only the mobile device [5]. In this case information collected by a tag cannot be reused or combined with other tags [4]. This interaction style is called single-tag interaction.

Anyway some attempts have been made to rise above and make use of more than one tag during the usage of an application. Some examples, which will be explained later on, are Touch & Control [30], Collect & Drop [4] and Touch & Interact [14] [15]. Generally the interaction style used in those approaches is called multi-tag interaction. Consequently all this leads to new research questions concerning the interface and interaction design of multi-tag interaction applications. As a first step a preliminary classification can be established naming four different categories for multi-tag interaction: Navigation, Selection, Combination of Information and Mapping.

Applications implementing the category "Navigation" use tags to offer navigation and structure. Using "Selection" the user will have the possibility to select different options, which are used by the application, with the help of tags. "Combination of Information" provides an opportunity to combine different tags and in doing so one can create new information for the application to use. Making use of "Mapping", functionality that is used to control an application is mapped to a physical interface with the help of tags.

Aside from concrete examples for multi-tag interaction, this thesis wants to approach the topic from a more general perspective and focus on the interface and interaction design as well as the distribution of physical and mobile interfaces for multi-tag interaction. To achieve this, for three of the above mentioned categories - Selection, Navigation and Combination of Information - use cases and prototypes are developed and evaluated.

Evaluating "Selection" and "Navigation", a prototype for food ordering in a restaurant is developed, offering different meals for four courses. The second user study evaluates "Combination of Information" with the help of a city guide application, which offers the possibility to combine different sights and different actions. At last the evaluation of "Selection" and "Navigation" is refined using GUI widgets.

Each of these prototypes offers one solution using single-tag interaction and several solutions using multi-tag interaction. Conducting several user studies these prototypes are evaluated concerning attention shifts, execution time and errors alongside qualitative data provided by the subjects. As a result, best practices for the design and distribution for the mobile interface, as well as for the physical interface, depending on the application area, shall be given.

The document is structured as follows. Chapter 2 gives an overview on related work. Enabling technologies, like numeric identifiers, visual markers and near field communication (NFC), and interaction techniques for single-tag interaction as well as multi-tag interaction are evaluated.

Furthermore a classification for single-tag interaction is given. Finally some general usability requirements for physical mobile interaction are presented. Chapter 3, on the basis of already existing applications, tries to offer a classification for multi-tag interaction. To evaluate this classification, different user studies have been conducted. Chapter 4 describes the first user study, which aims at the categories "Navigation" and "Selection". Chapter 5 summarizes the conduction as well as the results of the second user study, which aims at "Combination of Information". Chapter 6 outlines the most important information concerning the third user study, which was a refined analysis of "Navigation" and "Selection" based on GUI widgets. Finally in chapter 7 the main results are summarized and an outlook for future work will be given.

2 Related Work

Physical Mobile Interaction is the interaction between the user, his mobile device and smart objects in the real world. Whereas a smart environment is an environment augmented with sensors, tags, visual codes etc., which offers the possibility for electronically operated devices to interact with everyday things [28]. Much research in this field is done concerning the interaction between smart environments and mobile phones. Mobile phones are part of most people's daily life. They carry them with them all the time and offer a "personal computing platform that is practically constantly accessible" [27]. Modern mobile devices offer higher computing power and include additional features like integrated cameras, motion sensors or radio frequency identification (RFID) [2]. This new technical options provide lots of new ways for the interaction between mobile devices and the physical environment, but therefore there also arise many new questions concerning usability and interaction patterns [16]. Mobile devices support discovering, capturing and using information. E.g. they offer the possibility to access related information, like providing the TV program when the TV is touched or they can engage the role of a remote control and therefore add interaction capabilities to objects, which do not offer a user interface [27].

Despite all these possibilities these ideas have not found their way in everybody's daily life yet. This is partly because of the non-existence of commercial consumer applications [2]. Anyway there are already different existing technologies available, which are evaluated in the following. At first different enabling technologies, like visual codes and near field communication are presented along with different interaction techniques. Furthermore there do exist some classifications of different physical mobile interaction areas. The last part of the related work section will cover already recorded usability aspects.

2.1 Enabling Technologies

To offer interaction between mobile devices and everyday things, everyday things have to be equipped with some machine readable tags. Those tags support discovery and interaction, hence they "act as bridges into the digital domain" [4]. Different technologies are available, which all aim for more intuitiveness, simplicity and convenience whilst interacting. Anyway, studies show [2] that all these technologies are still mostly unknown to the subjects.

2.1.1 Numeric Identifier

Numeric Identifier [4] is the simplest enabling technology. Basically, objects, which offer additional information are tagged with a number or another clear identification symbol. This number or symbol can be typed into the intended textbox of an application. The application will know, which number is linked with which object and maps both the way it is needed for the application.

2.1.2 Bluetooth

Two requirements have to be fulfilled to be able to use Bluetooth [28]. For once the mobile device has to provide bluetooth support to scan for close by bluetooth enabled devices. Furthermore each smart device, which should be available for interaction, has to be represented by at least one Bluetooth access point, which holds information about it.

Having used the scan functionality of the mobile device, the user can select and access the provided objects.

2.1.3 Infrared

Infrared is a technology, which makes use of electromagnetic waves. By using infrared beams the interaction technique "pointing", which will be described in more detail later on, can be realized

[28].

Furthermore infrared beacons, which are small infrared transceivers, can send information to mobile devices, which are able to process the provided information [18].

2.1.4 Location-based

Location-based enabling technologies comprise a set of different technologies to detect the users position. One possibility is the widely known Global Positioning System (GPS), which is based on satellites. To use GPS the mobile device needs to have a GPS receiver, which can calculate the actual position with the help of the GPS data. An example for the usage of GPS is "Bill - a Seamful Mobile Game" [3], where users collect coins to earn credits for their team.

Another technology is based on the user's cell-id. Based on GSM, by knowing the location of the radio cell the mobile device is currently registered, one can approximate the current location of the mobile device.

2.1.5 Visual Markers

Visual markers, like shown in figure 2.1, are detectable in a very low resolution like 160*120 pixels and usually have a capacity of 76 bits [26]. They are a so-called pull technology [2], which means the user has to explicitly point his mobile device at the visual marker and seek the information, which is stored in it. The visual marker is an image, which encodes data that can be scanned by the camera of a mobile phone. Different implementations do exist, meaning that in some cases the user actually has to take a photo of the marker, while in other cases the mobile device is able to recognize the marker in real time in the live camera image and decodes the data [26]. Depending on the recognition algorithm it is possible to detect multiple markers at once.

Figure 2.1: Examples for visual markers. The left one is a so called QR Code while the right one is a Semacode [19]. Other visual markers do exist.

2.1.6 Near Field Communication

Near field communication, or short NFC, is a short range wireless technology and a so-called push technology, meaning it actively transmits information to the phone just by being close enough to the NFC reader [2]. Close enough typically means less than 5 cm. An NFC-tag, which can be read but also be written on, can store small amounts of data (about 1/4 Kbytes) [13]. Normally those tags do not contain a power-source, therefore they are passive. Active tags with some kind of battery have a wider communication range. Every tag carries at least an identification code [31] but furthermore they typically contain links to other services by storing an url or any other information, which can be useful within an application, therefore NFC-tags can trigger other services.

Different modes are available: In reader/writer mode an NFC device, like a mobile phone equipped with an NFC reader like the Nokia 6131, can read data from or write data on an RFID tag. Using the peer-to-peer mode, two devices can exchange data just by being close enough together and therefore establish a wireless link. In card emulation mode the NFC equipped mobile phone itself can act as NFC-tag. The big advantage of this is that the mobile device offers a secure data storage to be used by any application like for example eTicketing or contactless payment [22].

NFC-tags can be used to offer quick access to available services in the surrounded environment without the need for any configuration. Using this technology, it is easy to interact with fixed devices [22].

By now there are only very few NFC equipped mobile phones available on the market. The Nokia 6131 NFC is one of them. Another, but very old model of Nokia, the Nokia 3220 could be extended with an NFC shell to support NFC technology. Anyway, while this technology is hardly known in Europe, these phones are already widely used in some Asian countries [14].

User studies show that people are uneasy about the broadcast nature of RFID and are afraid of accidently picking up information. Regarding usability, untrained users consider it more easy to use visual markers like 2D barcodes, but the handling of the NFC technology significantly improves after some training [2].

2.2 Interaction Techniques

The previously described enabling technologies are used to enhance the physical environment and therefore offer the precondition for physical mobile interaction techniques, which are supposed to be more natural than traditional input methods like input via the keypad of a mobile phone.

All in all different levels of interaction and several interaction styles are possible. Typical user scenarios include tasks like accessing information by touching a tag or initiating an information channel like bluetooth or an internet connection [2].

Interaction with NFC-tags normally is done by some kind of physical gesture like touching a tag or pointing at it. Most currently available applications focus on very simple interactions using only one single tag to initiate a service. This paradigm is also referred to as Touch-'n-Go service interaction [15]. But there are already other use cases in development to make use of multi-tag interaction. One possible approach is Touch & Interact [14] [15], which will be taken into account later on.

2.2.1 Basic Physical Mobile Interaction Techniques

Physical mobile interaction is characterized by the interaction style between a mobile device and the physical environment [27]. A so-called physical object can be anything, for example a real world object, a person or a location. The intention of physical mobile interaction is the simplification of service discovery and furthermore offering new kinds of object-, person- or location-based applications by removing known limitations of mobile phones.

Touching

Being similar to every day actions, touching is considered to be the most intuitive physical mobile interaction [27]. Touching means to bring a mobile device and a real word object close together or in contact as depicted in figure 2.2. Usually some kind of feedback (e.g. vibration of the mobile device), is given, if the touching was successful and the mobile device was able to read the tag, which enhanced the real world object.

This technology usually is implemented using radio frequency identification (RFID) and near field communication (NFC), which have the benefit that devices do not actually have to be in physical contact but be close [28]. This technology usually works at a range up to 5 cm.

Comparing it to other basic physical mobile interaction techniques like pointing or scanning it is very error resistant and users being asked stated it to be very quick, enjoyable, reliable, simple and secure with only little cognitive load [27]. They were able to learn this technique very fast and did hardly make any errors.

Figure 2.2: Using the physical mobile interaction technique "Touching" [5].

A big influence concerning the popularity of a certain interaction technique is the necessary physical effort the user has to superimpose [27]. Therefore this technique is preferred by the user in cases where the smart object is in direct reach. Especially at home people tend to avoid extra physical effort. This effect is not that strong in cases of sensitive actions. People tend to accept extra effort if they are sure that this extra effort provides more security for their interactions.

Furthermore another big advantage of this technique is the high accuracy, especially if there is a need to select tags, which are small or close together [28].

Pointing

As the name of this physical mobile interaction technique already suggests, the mobile device is pointed at a smart object to interact with it. Consequently it is a direct interaction technique, which is intuitive because it is known from every day interaction.

Technically speaking, pointing can be realized in many different ways [28]. A possible solution are visual markers, which can be detected by the device's built in camera, as shown in figure 2.3, and will be processed by image recognition technologies or light sensors, which react to laser or infrared beams. All these technical realizations usually offer a distance range up to 60 cm.

Figure 2.3: Using the physical mobile interaction technique "Pointing" [5].

The big disadvantage of this technique is the fact that the object or tag has to be in line of sight. But in contrast to touching there is no need to be directly next to it [27]. Consequently this interaction demands less physical effort. Compared to the ensuing technique called scanning, pointing is preferred although touching is considered to be quicker. Furthermore users describe pointing as innovative, enjoyable, and intuitive but according to them it does need more cognitive effort than touching and higher coordinative effort is required.

Prototypes showed that performance and error resistance is highly dependent on the actual implementation.

Scanning

Scanning offers the user the possibility to get a list on his mobile device of all smart objects, which are nearby [28]. Typically a wireless technology, like for example bluetooth, is used to create the list. This can be implemented in two different ways. Either the action of scanning is triggered explicitly by the user or the mobile device scans automatically and permanently for smart objects in the direct vicinity [27].

Scanning compared to touching and pointing is rather technical and furthermore, in contrast to the two previously described it is indirect, which makes it less intuitive for the user and takes more time during execution. Consequently users tend to apply a direct method, like touching or pointing, in cases were line of sight is given [27]. The one scenario in which scanning is preferred is to overcome physical distance and physical effort, meaning if the user would have to move otherwise, he accepts the rather technical approach.

Scanning requires higher cognitive load due to the fact that a mapping between the list and the actual smart object has to be established [27]. The risk is very high that the user might accidentally interact with an object he did not intend to interact with. This is also due to the fact, that a list usually displays all available options and not only the ones, which are important for the user right now [28], although this problem could be solved by the implementation of this technique. On the other hand it is also an advantage that all nearby objects can be displayed [27]. The user will not miss objects he could use to interact with and furthermore no visual augmentation is needed to attract the user's attention.

User Mediated Object Interaction

User Mediated Object Interaction is already quite well known and is already in use [27]. Especially museum guides are often based on this interaction method. Objects provide information e.g. a number, which is then typed into the mobile device to establish a link between those two, as shown in figure 2.4. Therefore no special technology is needed, which also makes this technique very reliable and simple to understand and use.

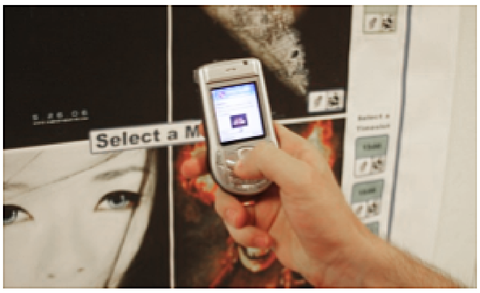

Figure 2.4: Using the physical mobile interaction technique "User Mediated Object Interaction" [5].

Considering the performance of this interaction technique, it is important that the length of the information that has to be typed into the mobile device is rather short.

Hovering

Hovering [34] is inspired by the visualisation of hyperlinks in the web. Similar to touching, the user holds his mobile device close to the NFC-tag. But by doing so he does not select the tag, but is displayed additional information about the tag on the display of his mobile device as depicted in figure 2.5.

Figure 2.5: Using the physical mobile interaction technique "Hovering" [34].

As already mentioned this interaction technique is inspired by web browsers and their handling of links. Hovering over a link in a web browser usually results in displaying the url in the status bar and if available also the title of the link as tooltip. Consequently hovering one's mobile device over a tag, one can quickly check the content of different tags before selecting one.

In the application, which is presented in [34], the user can choose between two different views: single and list. In the single mode the user is only displayed the data of one link, but there is more information about this single link than in the list mode. List mode shows more links. In this case, the user can select each link and access further information. In both views, the user can activate a link, e.g. viewing the information or calling a contained phone number, by pressing the select button.

In any case NFC records store the data in different fields on the tag.

2.2.2 Advanced Physical Mobile Interaction Techniques

Previously described physical mobile interaction techniques only describe one single interaction with one single tag. To take this one step further, in the following an overview of multi-tag interaction will be given [4].

One possible scenario of this extended mobile interaction is the reuse of information in different applications. Furthermore restrictions and limitations, like the small screen size and unpleasant input options, which are accompanied by the usage of mobile devices, can be bypassed.

Generally, advantages of multi-tag interaction are that the user can choose from more options on one smart object, which offers many more possibilities for designing the application. Consequently much more thoughts have to be put into the question, which elements should be part of the physical interface and which parts should by carried out using the mobile interface. Furthermore the arrangement of the tags on the physical interface is an important element.

All in all, multi-tag interaction denotes the usage of more than one tag for a "collective purpose" [4]. Research that has already been done in this area will be presented in the following.

Selection Techniques

In [25] different selection techniques for multi-tag interaction are proposed. At first participants were asked to select items on a paper map deliberately without giving them any further instructions. The goal was to see, which possible ways they would try to use. The result of this experiment was that most users pointed the mobile device on an item and pressed a button on the mobile device.

Anyway there are many other possible selection techniques, which can be envisioned. In a second experiment the users where presented five different selection styles: click-select (touching an item and pressing a button), path select (pressing a button at the starting point, dragging the mobile device along the desired path and releasing the button to finish the selection and selecting the whole path), multi-select (similar to click-select but by pressing a button more than one item can be selected), lasso-select (similar to path-select but start and end point are the same and everything inside the path is selected) and menu-select (before interacting with the map an information category is selected via menu, afterwards the actual selection is done by using one of the previous techniques).

Furthermore audio and visual feedback was included in this prototype to make selection easy to understand. E.g. an orange trail was shown along the selected path or a sound played once the selection was finished.

The interesting thing about this second study is that although people used click-select if given no instructions, once they were familiarized with the other techniques there was no tendency towards click-select to be witnessed. Consequently they adapted the new techniques very easily.

Point & Shoot

Point & Shoot is described as "phonecam-based interaction technique for large public displays" [1]. The technique uses visual codes, which are shown on the large display, to offer an absolute coordinate system instead of tagging individual objects.

The integration of the visual codes is possible in different ways. The simplest way would be to integrate the visual codes directly onto the application's design, but this might bug the user and interfere with the overall optical impression. Another solution is to show the visual codes for a short moment on the display the minute the users issues the mobile device to select an item. A problem in this approach arises when offering a multi-user application. Other display technologies will offer the possibility to add the visual codes in infrared. This makes them readable for the camera but invisible to the human eye.

Figure 2.6 shows the user interaction with Point & Shoot. To select something the user is supposed to aim the phone's camera at the target on the large screen. At the same time the contents of the aimed area appear on the mobile device's display. Therefore the mobile phone acts as a viewfinder. By pressing the mobile phone's joystick one "shoots" a picture and therefore has made the selection, which will also be shown on the display.

Figure 2.6: Interaction using Point & Shoot [1].

Generally the minimum requirement issuing a selection is to at least include one visual code in the selected frame.

A huge advantage of this technology is the fact that perspective distortion, which can be caused due to the mobility of the mobile device, does not cause any problems.

Touch & Control

Touch & Control [30] is based on the REACHeS platform. This platform offers the possibility to turn "any mobile terminal with internet access into a universal remote control" [30]. At first REACHeS was combined with RFID-tags, which started the service. Touch & Control extends this idea and aims on building a complete user interface using tags. Consequently the user interface is not shown on a display but is incorporated in the physical environment surrounding the user. Anyway the current status of the application is only shown on the mobile phone's display.

The user interface is made out of a control panel with icons for each command, which are enhanced with RFID-tags. Touching one of these icons and consequently one of those tags, a command, more specified a HTTP request containing the target service, an event and some extra data, is sent to the REACHeS platform. The sequence, which is carried out by the platform in the following is depicted in figure 2.7 (for more details see [30]).

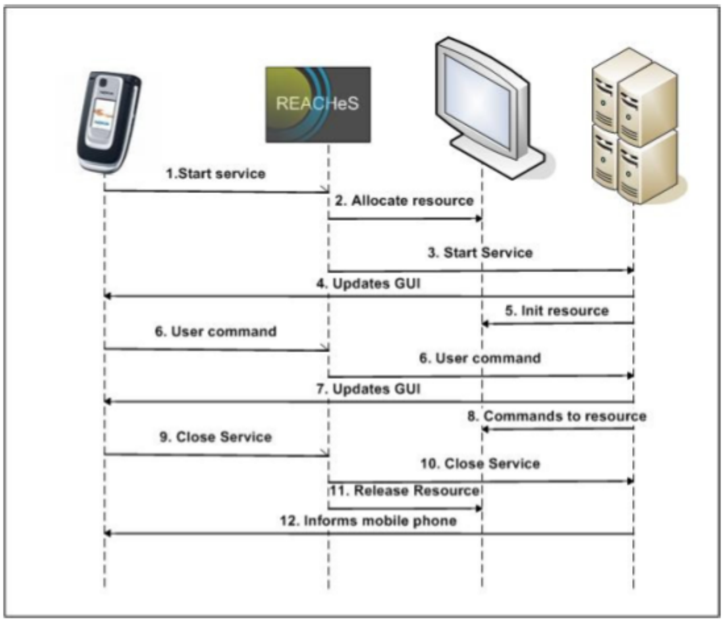

Figure 2.7: The sequence diagram for REACHeS, which is triggered by touching a tag [30].

All this is hidden from the user. He experiences the tags like mechanical buttons and only sees the results as for example a video being stopped.

Touch & Control is applied to a multi-media player by the developers in a prototype. Anyway the technology can be applied to many use cases. A further positive effect is that the user interface can be very easily personalized because it is not a hard coded software component. All that needs to be changed is the graphical design of the control panel.

Collect & Drop

Collect & Drop [4] is described as "generic technique for multi-tag interaction, which supports the collection, storage and management of information from the real world as well as its usage with different services". The basic idea is to offer a framework, which provides the possibility to reuse tags and collected information throughout many different applications and services. Therefore Collect & Drop suggests the distinction of two different tags. Action Items and Data Items. Figure 2.8 show a user interacting with an application, which uses Collect & Drop.

An Action Item is used to define a service or an application, meaning it contains information, which is needed for its execution e.g. the reference, interaction protocol or which parameters need

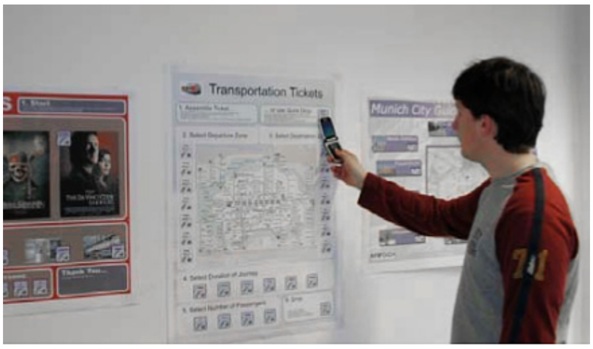

Figure 2.8: A user interacting with the poster of an application, which uses Collect & Drop [4].

to be provided.

Data Items consist of the actual parameter information, which is needed by the different applications.

Technically those Data and Action Items, which are collected, are stored in so-called Collections on the mobile phone itself. Those Collections are intended to put all items in an organized structure and are responsible for the invocation of a service, which was beforehand described in an acquired Action Item.

The interface of the Collect & Drop client contains four elements: Collection List (with all collections), Item List (which gives an overview of all existing items in one collection, ordered in the two groups Action or Data Items), Action Execution Screen (which asks for confirmation about any action the user wants to perform), and Action Specific Screen (shown after selecting "Execute" on the previous screen, technically the interface control is given to the respective action component and therefore this new component is responsible for the screen presentation and can show its own interface and control commands).

Concerning the actual tags, which are used for the real interaction, there are two different tags to consider. Firstly there are Hybrid Tags. They combine both, Action and Data Items on one tag. The reason for this mesh up is to make the interaction easier for the user because there is no need to know what kind of tag this actually is and so they cannot be confused. Secondly there are Drop Tags. Drop Tags are only associated with Action Items and they have to be explicitly touched to trigger an action. An extension of the simple Drop Tag is the Quick Drop Tag. It provides a short cut to a service because it already contains all Action and Data Items for one service. User studies showed that Hybrid Tags are preferred due to simplicity, speed, intuitiveness and comprehensibility.

Furthermore cross-object-interaction is supported. E.g. a Data Item from the city guide poster could be reused with the public transportation poster to get a ticket exactly to the desired point of interest. This interaction technique is quick due to the fact that Data Items are already stored on the mobile device and there is no need to collect them again.

Touch & Interact

Touch & Interact [14] [15] is an advanced physical mobile interaction technique, which resembles interaction with touch screens. The idea arose due to the fact that large displays have been very much improved in the last years. Their size is bigger, the resolution is higher and they are not as expensive as they used to be. Such screens can either be passive or active. A paper map can serve as passive screen whereas public screens or remote PCs are active screens. Touch & Interact itself is intended for dynamic displays and direct manipulation on them. In other words the mobile device is replacing the stylus and the dynamic display is replacing the PDA. Therefore the problem with the limited visual output of a mobile device is overcome. The display of the mobile device offers additional information and help, which is displayed when hovering tags. Furthermore haptic feedback informs the user that there is something new on his phone's display. Moreover audio feedback is used to alert the user in case an error occurs.

By touching the dynamic display with the mobile phone on any position, a link between those two is established and a selection is performed. Two different selections are possible. Select & Pick, as in figure 2.9, means touching e.g. a picture with the mobile device and the picture is picked up and stored on the mobile device. This interaction is very intuitive due to the fact that one is used to this kind of behavior from every day life. The inverse selection technique is Select & Drop, shown in figure 2.10. In this example the user can drop a picture on a screen by touching the screen on the destined location.

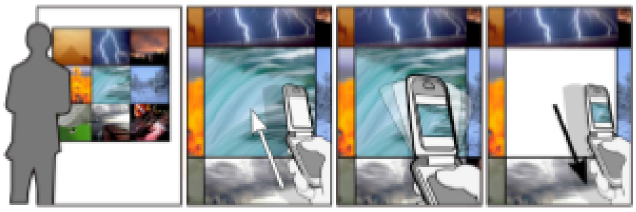

Figure 2.9: Select & Pick using Touch & Interact [14].

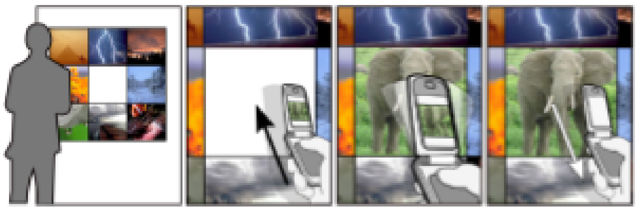

Figure 2.10: Select & Drop using Touch & Interact [14].

A prototype was implemented, which all in all supports seven generic interactions: Hovering offers the possibility to bring the mobile device close to a tag and by doing so the mobile device displays additional information on the mobile device's display itself. As already stated there are basically two selection options. Those two have been expanded in the prototype. Select & Pick is realized as basic selection technique by pressing a specified key on the mobile phone's keypad to select a tag as well as Multi-Selection where more than one tag can be selected by holding the key the whole time. Another approach is Polygon-Select where the user can select points by holding a specified key and after releasing the key all tags, which are inside the selected area, are picked up. Pick-and-Drop puts an item, which was stored on the mobile device, on the dynamic display. Beside that, Remote Clear is implemented, which deselects all tags, which are selected right now remotely, which also helps to reduce fatigue that easily arises using pointing interactions. The last basic interaction is the Context Menu. It is displayed on the phone and by using the phone's keypad different options can be selected. Therefore the main screen is not cluttered and users are already used to interaction with menus like that.

All in all the big advantage of Touch & Interact is the combination of the mobile device and the dynamic display. Although mobile devices are often said to be a problem due to small screen size and uncomfortable input modalities they can also enrich the dynamic display due to the fact, that they offer many different possibilities for input like joystick or buttons and their output modalities can be used for haptic or audio feedback. Furthermore sensible data can be stored on the mobile device alongside contextual data. Moreover it can be used to make multi user access possible by phone identification. Also access privileges and billing can be realized with the help of the connection between user, mobile phone and dynamic display.

Anyway one big disadvantage is the low input resolution. E.g. using this technology for a map with different points of interest, it is very likely to happen that there is more than one marker in the range of one single tag. In the implemented prototype this problem was solved by enlarging one tag into nine tags and therefore selection was possible with the normal approach, but other solutions are possible. For example after selecting a tag with more than one point of interest a key on the mobile device could be used to scroll through all possibilities and select the desired one. It depends on the number of markers hidden behind one single tag if this approach's performance is bearable. Another idea is to divide the tag hypothetically in nine areas, which are mapped with the keypad of the mobile phone and each area can be accessed by pressing the corresponding number on the mobile device.

Besides the described Touch & Interact technology, there are other possibilities to realize this interaction. One could combine a traditional touchscreen and a mobile phone or a conventional display could be controlled remotely by a mobile device. Comparative studies showed that Touch & Interact performs much faster than the other two options. Furthermore users rated Touch & Interact higher concerning ease of use, intuitiveness and enjoyment.

All in all Touch & Interact can be applied to many use cases. Possible scenarios are interaction with shop windows, vending machines, maps, public displays, interactive surfaces or other information displays.

2.3 Classification of Physical Mobile Applications

Physical mobile interaction can be applied to many areas. Typical application ranges are for example reading URLs from visual markers, mobile payment with the help of NFC, mobile advertisement via Bluetooth or other more complex 2-way interactions e.g. with an airport check-in terminal [16].

In the following the most important areas of physical mobile interaction are named and briefly explained.

2.3.1 Presentation of Information

The most basic physical mobile interaction is to read information from a tag, which is located a on physical object and therefore provides more knowledge about this object [16]. The user himself decides what he wants to do with the acquired information considering the available options.

Usually these kind of tags can be found on posters, leaflets, museum guides or any kind of information point.

Users themselves report this interaction technique to be fast, simple, direct, and interesting. They state that they would use it to acquire information and consider it to be positive that they do not need to search the internet to get the particular information.

2.3.2 Physical Hyperlinks

NFC-tags or any other tags can also act as physical hyperlinks [16], meaning they offer a shortcut to a service or application and therefore minimize interaction complexity e.g. opening a link in a web browser or calling a phone number after touching a tag. This strongly helps to enforce one of the main goals of physical mobile interaction: simplicity.

Considering the technical implementation of NFC and physical hyperlinks this can be done via the so called push registry. Users call this interaction style fast, simple and handy.

In [11] a slightly different categorization is applied, which combines physical hyperlinks and the presentation of information in one single category. Barcode scanner are named as metaphor, which - like physical hyperlinks or tags containing any other information - only support 1-way communication to access additional information.

2.3.3 Tagging

Tagging [16] means to actually write information on physical objects respectively on their tag. But actually it is problematic that mobile devices offer more options to read tags than to write on them. Hence tagging mainly focuses on RFID- or NFC-tags and geo-tagging.

Users call tagging to be simple, time saving and error reducing. They would be willing to use it to provide information for other users. Furthermore they argued for autocompletion because it makes the input a lot faster but they want to keep the possibility to edit the suggested data.

2.3.4 Broadcasting

In contrast to the previously mentioned application areas, broadcasting actively pushes information to the client [16]. This can be done with technologies like for example Bluetooth or active RFID-tags. Additionally this technology has to be activated on the mobile device. But even though users have to explicitly start the technology it could easily happen that they do feel spammed by the application. One possibility to prevent this, is to filter the information according to a previously supplied personal profile or preference. This technology is typically used by information points or mobile advertisement.

Asking users about this application area they emphasized their fear of being spammed but acknowledged that they might receive helpful, interesting and valuable information.

2.3.5 Tag Emulation

Another possibility for a mobile device is to act as tag itself [16]. This is supported by the NFC technology, which offers the possibility for devices to be passive and to be readable by active readers. Typical applications, using this technology, are smart cards used for identification, ticketing, access control and payment.

Another possibility to acquire tag emulation is by showing a visual marker on the mobile device's screen, which can than be read by other devices.

All in all one can say that tag emulation is the complement to tagging, which requires the user to actively write information in contrast to passively providing information for other active readers.

Users considered tag emulation as comfortable and time saving but concerns were risen because of the possibility of the misuse of customer data.

[11] also states this application area and calls it "Verification for Services". Their metaphor is a paper ticket or - considering payment - a credit card.

2.3.6 2-Way Interaction

The previously mentioned use cases emphasize the simplicity of physical mobile interaction. There are only two possibilities. Either the information is provided or information is acquired by the user and his mobile device. There is always only one single interaction step but more complex tasks are actually imaginable, which include the execution of many steps in a row and bidirectional communication with different smart objects [16]. This is called a 2-way interaction.

Possible examples are a check-in terminal at the airport or mobile payment, which can consist of more than one step.

Users stated it to be simple and mostly fast, because in contrast to normal desks there are usually no waiting queues. On the other hand the missing human contact was also criticized. Others just considered the interaction with multiple tags as laborious.

The equivalent in [11] is "Peer-to-peer sharing" with the corresponding metaphor cable, which is supposed to be similar to a NFC established connection. Furthermore there is a strong emphasize on a certain goal when 2-way interaction is applied.

The previously mentioned Collect & Drop [5] technique also strongly hints at 2-way interaction with their division of tag into parameter- and action-tags, which supports the interaction between several tags.

2.4 Usability Requirements

Different user studies pointed out some common problems users had while interacting with NFC-tags. To minimize those problems and use the power of physical mobile interaction to its full extent one should keep those in mind.

For many participants the initial point of the interaction was unclear [11]. Using a start-tag to launch an application is a new interaction technique most users are not familiar with. Furthermore the sequence of interaction as well as the exact state of the interaction is confusing for many people, because tags usually do not force a strict order on the user, as for example a navigation with "back" and "next" links. This could be solved by giving appropriate feedback on the mobile device as well as on the fixed terminal if possible. These problems go hand in hand with the fact that people have problems building a mental model for this kind of interaction [2].

The usage of tags is not really clear to many people. Are they supposed to hover, slide, wave or press the mobile device on the tag [22]? Some hold the mobile device longer near the tag than actually necessary or asume they have to keep the mobile device there the whole time [5].

Furthermore some people feel embarrassed or awkward by touching a tag and therefore waving their mobile device through the air [2]. They have the feeling of drawing too much attention on them.

Generally security was a concern of many users. Especially the "always on" status of the reader made some users feel uneasy [22]. Information, which data is transmitted or stored, would probably help the users to feel more comfortabel.

3 Analysis

In the previous chapter, dealing with the evaluation of related work, one can clearly see that up to now the focus has been strongly on single-tag interaction. Concerning single-tag interaction [16] as well as [11] already gave a classification of the different application areas, which have been summarized in section 2.3.

Anyway there do exist some approaches dealing with multi-tag interaction, as already stated in 2.2.2. Having a closer look at those, one can derive some characteristics for multi-tag interaction.

In general multi-tag interaction is "physical mobile interaction with multiple tags that are targeted at the same interaction process" [4]. Those tags can be spread on one single smart object or on many different ones. In all multi-tag interaction application areas, parts of the mobile interface are transfered to a physical interface, to ease the overall interaction process and overcome the shortcomings, like small displays and cumbersome input possibilities, of mobile phones.

In the following a classification of different application areas for multi-tag interaction is presented. Four different categories can be extracted: navigation, selection, combination of information and mapping.

3.1 Navigation

SmartTouch and their "Restaurant Pannu" example [32] is a classical multi-tag approach, which uses tags to offer navigation. As figure 3.1 shows the user can order his meal by touching different tags. In doing so jumps to different categories to order the desired food from.

Figure 3.1: The SmartTouch application "Restaurant Pannu", which makes use of tags for navigation [32].

Another application offering navigation is presented in [26], which shows a visual code menu.

Although of course there is a difference in using visual codes compared to the NFC technology. No matter if using visual codes or NFC, one can use tags to structure an application and therefore having different entry points for an application by offering different tags. After having jumped to the desired part of the application, any further interaction will be carried out on the mobile interface.

The big advantage of using tags for navigation is that the user does not need to click through a long structure of "next" and "back" buttons or use the tiny options menu, which mobile applications normally provide. Furthermore there is no real possibility to give some information for each category on the mobile device, whereas this can be easily placed on a tag-enhanced poster and the user can therefore decide more easily, which category is the right choice for his task.

Generally navigation is an interaction specific example for multi-tag interaction, meaning the implementation does not depend on each individual application, but will have a very similar realization in every use case.

3.2 Selection

"Selection" is already implemented in the prototype "mobile interaction with advertisement posters" of [6]. A poster enhanced with some tags has been created, as shown in figure 3.2, which offers the possibility to buy tickets for a movie. During the ordering process the user will have to choose his movie of choice, the desired cinema, the number of seats and the preferred time slot, all by touching the corresponding tags on the poster.

Figure 3.2: The movie ticket poster, which offers the possibility to select the movie, the cinema, the number of seats as well as the preferred time slot [6].

A prototype, which was used to implement Touch & Interact [14] [15], made use of a 10x10 mesh of tags, which supported selection. Users could move their mobile device over the mesh and select different items, which were presented on the overlaying poster or some kind of dynamic projection. In this case one prototype was a picture board where users could upload or download pictures onto their mobile device, another one was a tourist guide application using a tag-enhanced map.

Another approach using multi-tag interaction for a selection process is presented in [12]. The NFC technology is incorporated in the meal delivery of a home care service. Each day the user is supposed to touch one of three tags, choosing between two menu options or the option "no meal". Their choice is automatically transferred to the home care service and they will receive the food they ordered.

Making use of tag supported selection, the navigation through the application is carried out on the mobile device itself, whereas the selection is done by touching the desired tags on the physical interface.

Compared to the classical approach, where the user probably needs to scroll through a long list of items on the mobile device's screen, the user can select his choice by touching a tag on a poster. Of course the ease of selecting an item on a mobile interface on the mobile device's screen hugely depends on the way the selection is presented and implemented but in general a tag-enhanced poster might give a better overview than a list on a mobile device. It offers the possibility to show additional information to each item, like a picture or textual information.

All in all, "Selection" is considered to be an interaction specific example for multi-tag interaction.

3.3 Combination of Information

The prototype described in [25] consists of a paper map, which is enhanced with tags and has an additional menu on paper (see figure 3.3). In the associated user study the participants were asked to find out, which coffee shops are in a certain pedestrian area. This was supposed to be achieved by selecting "food and entertainment" from the tag-enhanced paper menu and afterwards selecting the area. Consequently both information, acquired with the help of two different tags, the category and the area, were combined to select the desired items.

Figure 3.3: The map of Halifax and the additional menu, which offer the possibility to combine information [25].

Collect & Drop [4], which was explained in more detail in 2.2.2, is a very good example for the pattern "Combination of Information". The idea behind Collect & Drop is the introduction of Action Items and Data Items, which can be combined. This idea has been evaluated with three applications: A movie tickets poster, a transportation tickets poster and a Munich city guide poster. In every scenario different kind of information is combined e.g. using the transportation tickets poster, one has to select the departure zone and the destination zone, the duration of the journey as well as the number of passengers. All this collected information has to be dropped afterwards on the dedicated drop tag and a ticket is acquired.

Compared to an application, which only uses the mobile device itself, the presentation of the different options on a poster, which can be combined, offers the user a better overview. Just with a short glance he can detect how many and which options are available.

Furthermore, the idea of combining different tags with different information after their collection strongly reduces the number of needed tags. E.g. in analogy to the transportation ticket poster of [4], the user has to choose from seven departure zones, seven destination zones, six different options for the duration of the journey and four different numbers of passengers, which makes a total of 24 tags. In contrast, if combination of tags is not possible, every combination would have to be presented on a separate tag, which would result in 1176 different tags, which is an absurd idea.

Generally two different types of combination are possible. One can combine different information from the same type as in the transportation ticket example, or one can combine information from different types e.g. the example presented in [25] where on the one hand items are chosen by selecting a certain area and those items are combined with a second tag, which acts as a filter, and only choses the coffee shops from the previous selection.

All in all "Combination of Information" is an application specific example, meaning that the actual implementation strongly depends on the application's functionality and design.

3.4 Mapping

Already many applications based on physical mobile interaction use mobile devices to interact with smart objects. By touching them they often also are able to control those devices but this is mostly based on interaction with one single tag and an application on the mobile device, which is triggered by the tag. [27] uses this technique in their prototype "mobile interaction in smart environments" for devices, which do not offer any user interface themselves.

In [29] the REACHeS Framework is presented, which aims at mobile devices controlling multimedia players. Using this framework the user has a set of NFC-tags and can start services with the help of these tags e.g. starting a multimedia file in a player. Further input can then be done with the help of the mobile phone's keypad. Moreover the mobile phone's display is used to provide the user feedback and shows, which actions are currently possible. For example when controlling a multimedia player, the available options like stop, play, fast forward or rewind are shown on the display as buttons and the user can move between those buttons with the help of the arrow keys of his keypad.

Going one step further, it would also be possible to offer more than one tag to control an object. This is done with Touch & Control [30] where the interface for controlling the multimedia player is mapped on a physical interface as shown in figure 3.4. Control buttons like play, stop, fast forward and rewind are presented as NFC-tags and can be triggered by touching the corresponding tag with the help of a mobile phone. Additionally the status of the player can always be checked on the mobile phone's display.

Figure 3.4: A tag-enhanced multimedia player control panel [30].

Summing up, "Mapping" means to map interaction elements or widgets of an application one-to-one on a physical interface. Advantages are that the user has a graphical representation, which input is probably easier to handle, than controlling the "buttons" via the mobile device's keypad.

Once again "Mapping" is an application specific approach. Depending hugely on the application, the mapped physical interface will be designed totally different.

4 1st User Study: Navigation and Selection

In the following, a first prototype is designed, developed and implemented. The goal of this first prototype is to evaluate, which distribution of tags is preferred by the user. Different interaction elements are used to compare and find out, which one works best for the presented tasks and in which way, as mobile interface or physical interface.

In reference to the previous mentioned classification for multi-tag interaction, the categories "Navigation" and "Selection" are evaluated. The users are asked whether they favor to accomplish the tasks in a traditional way, meaning having to input everything with the help of the mobile phone's keypad or do they prefer to interact with an NFC augmented menu or even a combination of both. And in case of the latter, which steps do they want to execute directly on their mobile device and in which cases do they favor physical interaction.

4.1 Basic Use Case

The basic use case consists of a subject being in a restaurant "Osteria Italiana" and wanting to order his food with the help of his mobile phone. The mobile phone, which is supposed to be used to carry out the tasks, is equipped with a NFC reader, in this case the Nokia 6131 NFC. In all scenarios the user was asked to order four courses - appetizer, main course, dessert and drink.

The basic workflow is shown in 4.1. Having started the application the user sees a welcome-screen offering basic instructions about the application and its usage. Following, the user will select his preferred meal and drink in the four offered categories. Having made the selection, a summary is presented, which then is supposed to be submitted to complete the order. The successful completion will be confirmed to the user.

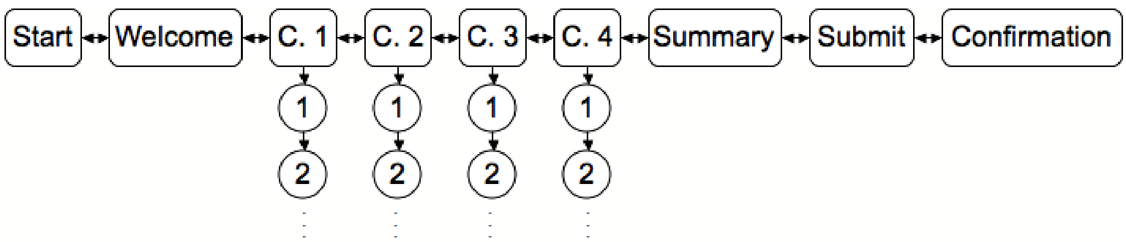

Figure 4.1: The basic workflow of the task belonging to the first user study.

During the study four different prototypes, which will be explained in more detail later on, are presented to the user to cover all possible combinations of navigation and selection distributed on the mobile interface and the physical interface. Figure 4.2 depicts, which prototype covers which combination. In this case, the multi-tag interaction category "Navigation" is mapped offering "Next" and "Back" buttons on the mobile interface or tags are placed on the physical interface, which lead to the different categories after touching.

The multi-tag interaction category "Selection" is represented by the different meals and drinks the user has to choose from. They are either presented as lists with radio buttons on the mobile interface or as tags on the tag-enhanced menu.

Furthermore there are four different scenarios differing in task and interface complexity. There are two levels of task complexity. Either the user just has to order four courses or he has to change his order before submitting, pretending to have changed his opinion and wanting to order something different. Interface complexity likewise has two levels. Either the list of options to order from consists of seven items or it consists of fourteen items.

In the following the four prototypes will be explained in more detail.

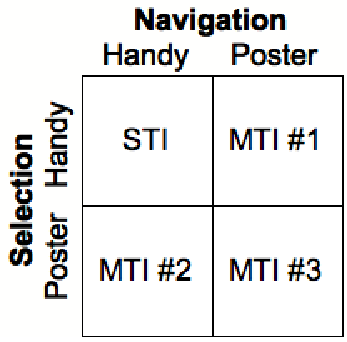

Figure 4.2: Covering all possible combinations of "Navigation" and "Selection" distributed on the mobile application and the physical interface.

4.1.1 Single-Tag Interaction

Figure 4.3 shows the tag-enhanced part of the first prototype. It just consists of one single tag, which starts the application after being touched. Depending on the data encoded on the NFC-tag either the application with low interface complexity - meaning the short list containing seven items to choose from - or the high interface complexity - meaning the long list containing fourteen items to choose from - is launched.

Figure 4.3: The tag-enhanced poster for Single-Tag Interaction consisting of one single tag, which starts the application.

Figure 4.4 shows screens of the mobile application belonging to Single-Tag Interaction. Once the application is started with the help of the NFC-tag, the user is presented the start screen (a) with basic instructions concerning the application. In this case the user can browse through the four different courses by using the left and right soft keys labeled with "next" and "back". To select the meal of his choice, lists with all possible options are presented for each course. Screen (b) in figure 4.4 shows both interface complexities, on the top low interface complexity with seven options and on the bottom high interface complexity with fourteen options, which also means that not all options can be viewed on one screen and the user has to scroll to get a complete overview. Once the user has selected his choice for all four courses, he is presented the summary (c). In case the user wants to change one or more of his choices he can still go back by pressing back. Once the user is satisfied with his choice he can send his order by pressing "Submit". Consequently a confirmation is shown (d) and the order is completed.

Figure 4.4: The mobile application belonging to Single-Tag Interaction.

4.1.2 Multi-Tag Interaction #1

Figure 4.5 shows the tag-enhanced part of the second prototype. This prototype makes use of multi-tag-interaction and offers six tags. With help of the first tag, the application is started. Corresponding to the prototype for Single-Tag Interaction, depending on the data encoded on the NFC-tag behind the symbol, either the application with low interface complexity (seven choices) or the one with high complexity (fourteen choices) will be opened.

Once the application is started, the user will be presented the first screen (a) shown in figure 4.6. Once again the start screen gives a short instruction about the usage. In this case the user is asked to touch further tags to order. By touching one of the four tags - "Choose Appetizer", "Choose Main Course", "Choose Dessert" or "Choose Drinks" - the user will be presented a list of different options for the selected category (b). After having selected one option and having pressed "Ok" on the left soft key the user is presented the summary (c) showing all already chosen options. The categories, which are not chosen yet, are left blank. By touching another one of the category tags, the user can progress his selection. In this prototype the order is not predetermined meaning the user can decide in which order he is touching the category tags and therefore in which order he selects the different courses. Being content with one's selection the user has to touch the submit-tag to send his order and after successfully sending he will be presented a confirmation (d).

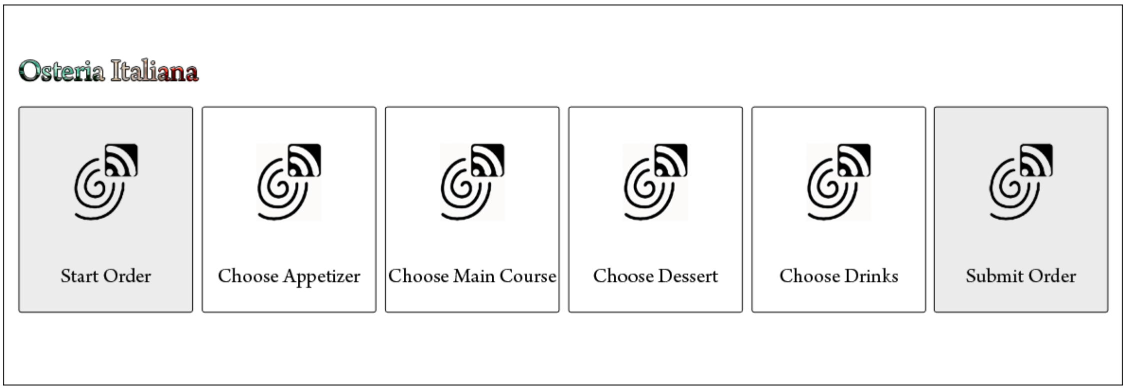

Figure 4.5: Multi-Tag Interaction #1 consisting of six tags. One start- and one submit-tag and four tags for each category.

Figure 4.6: The mobile application belonging to Multi-Tag Interaction #1.

4.1.3 Multi-Tag Interaction #2

Figure 4.7 and figure 4.8 show the menu for the third prototype. Depending on the complexity of the interface either figure 4.7 - supporting low complexity (seven choices per category) - or 4.8 - supporting high complexity (fourteen choices per category) - are presented to the user. In both cases all meals are represented by a NFC-tag and can therefore be directly selected by touching the corresponding NFC-tag. Multi-Tag Interaction #2 differs in the way the application is started. While all other prototypes are evoked by touching a special NFC-tag this prototype requires the user to start the application by going through the menu on his mobile phone.

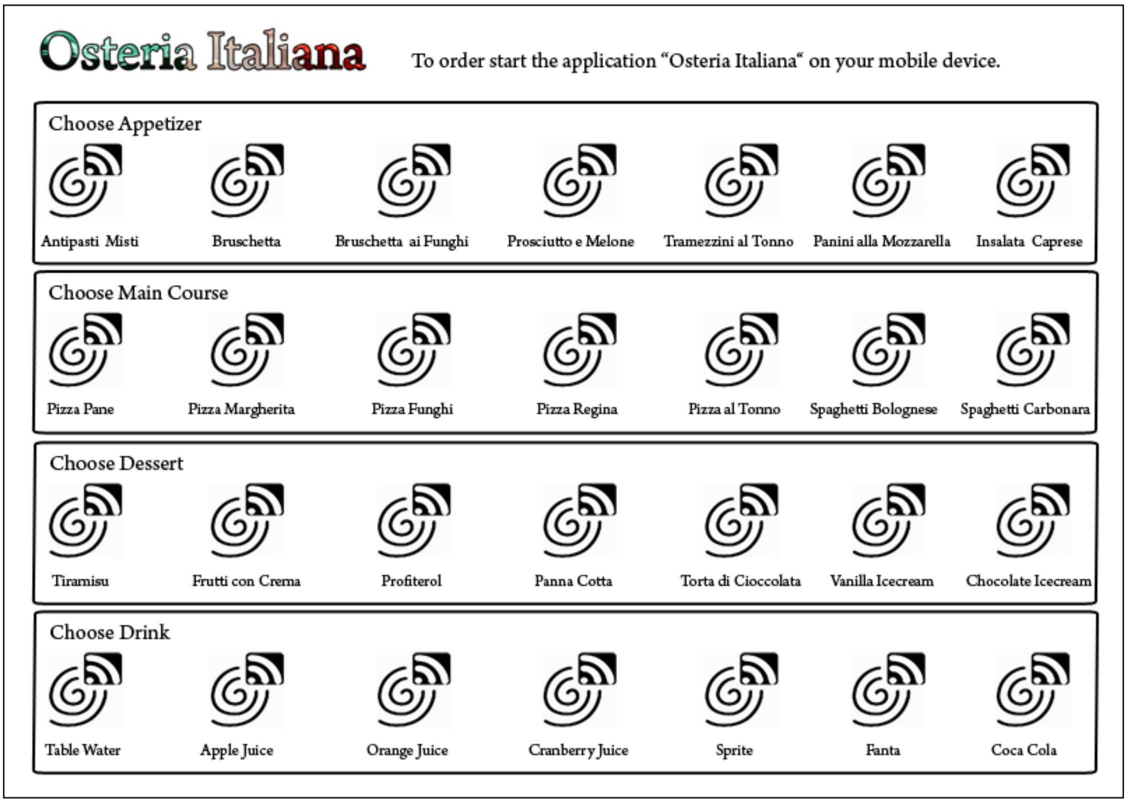

Figure 4.7: NFC-enhanced menu of Multi-Tag Interaction #2 with low interface complexity.

After the application is started the user is presented the first screen (figure 4.9 a), which gives him a short introduction about the usage. In this prototype the wizard pattern is implemented meaning the user has to select the food in the given order starting with an appetizer followed by a main course, a dessert and finally a drink. The application will guide him through this process by directly telling him, which course he has to select next (b). After each selection the summary is shown with all already selected categories. After having selected all four courses once again the summary (c) is presented and if necessary the user can press the left soft key to enter the correction-mode, which is the only possibility to change already selected meals in this prototype. Having pressed "Correction" the user does not have to follow any order and can change his choices by touching the NFC-tags of the meal he actually wants to order (d). Being happy with one's selection the user has to press "Submit" (the right soft key of the summary screen) and he will be presented a confirmation (e).

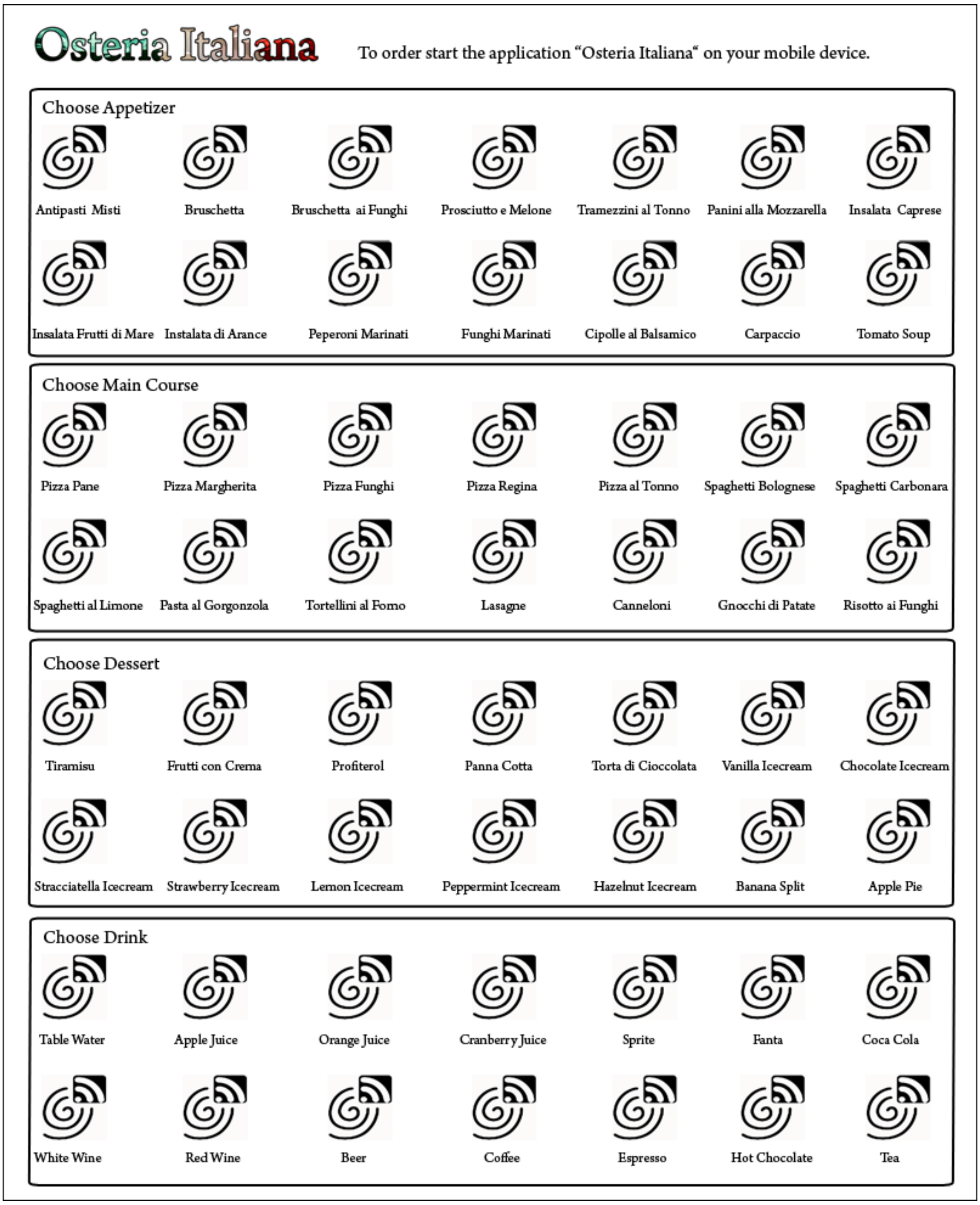

Figure 4.8: NFC-enhanced menu of Multi-Tag Interaction #2 with high interface complexity.

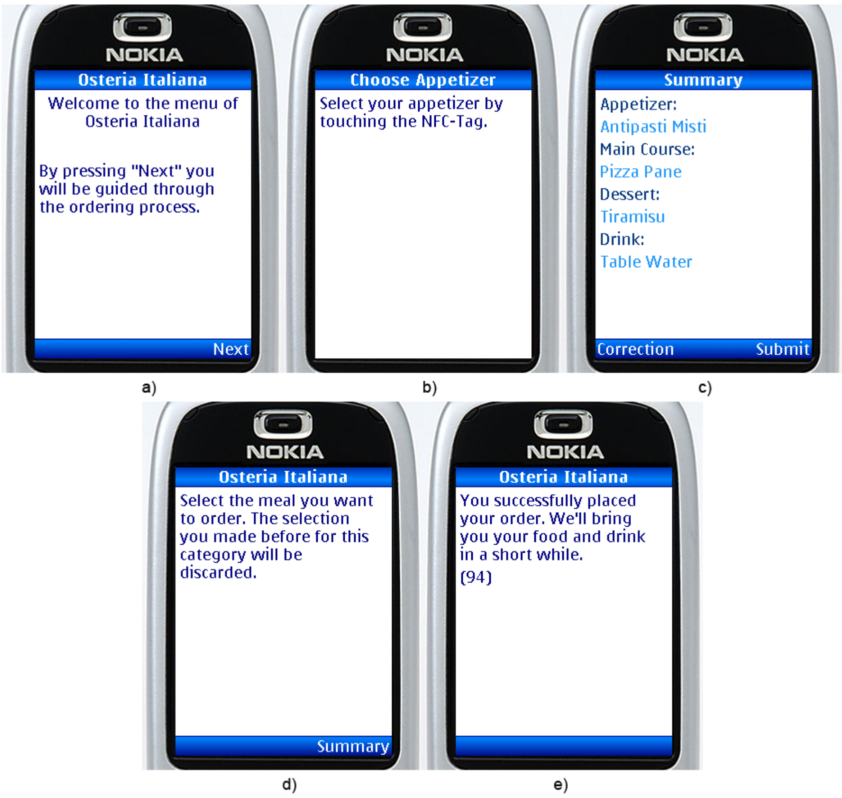

Figure 4.9: The mobile application belonging to Multi-Tag Interaction #2.

4.1.4 Multi-Tag Interaction #3

Figure 4.10 and figure 4.11 show the menu of the fourth prototype. Compared to Multi-Tag Interaction #2 it only differs in the two tags at the top of the menu to start the application and to submit the order. Consequently using this prototype the user does not have to use the menu but can once again directly access the application by touching the start-tag labeled "Start Order". Furthermore this prototype is not designed as a wizard like the previous one meaning the user can select each meal in the order he wants to do this. Moreover corrections can be done all the time just by touching a tag of a previously already selected category and the prior selected choice will be automatically replaced. Having finished the selection the order will be submitted by touching the corresponding tag with the label "Submit Order".

Like all other prototypes, the application starts with a short introduction on the start screen as shown in figure 4.12 (a). Having read it and after pressing "Ok" the user will see a blank summary (b), which will be filled with the selections while touching the NFC-tags. Once the user has selected all four courses and he has touched the submit-tag on the menu a confirmation (c) will be shown on the mobile device's screen.

4.2 Implementation

To carry out the user study the prototype had to be implemented. The prototype consists of two elements, the application on the mobile device and NFC-enhanced posters.

4.2.1 The Mobile Application

The mobile application is intended to run on the Nokia 6131 NFC (see figure 4.13), therefore development was realized using the Nokia 6131 NFC SDK 1.1 [20] [21] plugin for Eclipse [33].

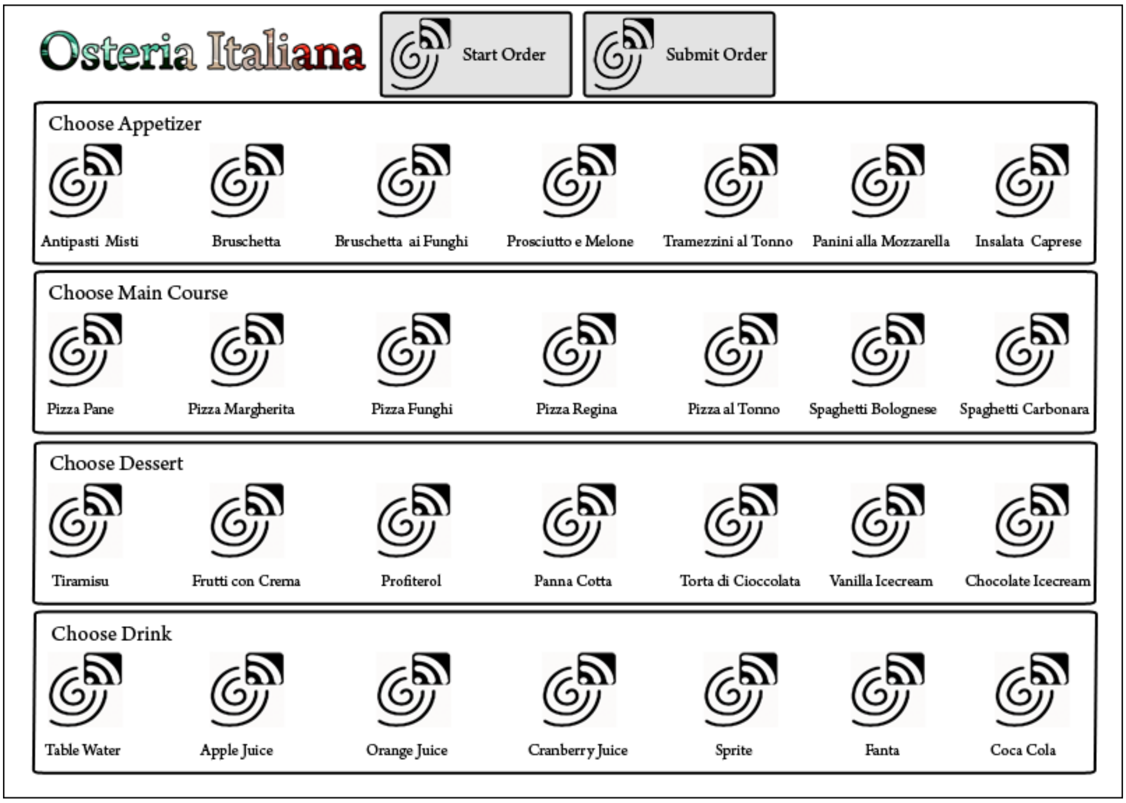

Figure 4.10: NFC-enhanced menu of Multi-Tag Interaction #3 with low interface complexity.

Implementation was done using J4ME [7], short for "Java For Me", which is an extension to the Java Platform Micro Edition (Java ME). The main focus of J4ME is on the graphical aspect of a mobile application, therefore the basic features of this mobile application are realized using Java ME, which of course incorporates the positive features of Java being platform independent and therefore running on nearly every mobile device, which is available today. Anyhow this also leads to certain problems. Java ME and its user interface framework LCDUI does not support a lot of possibilities to change the appearance of a mobile application but offers the possibility to adapt the look and feel of the device the application is running on.

In this special case that means that one is not free to assign the labels and functions to soft keys the way one wants them to be. Using the Nokia 6131 NFC the consequence is that as soon as the left soft key offers any functionality a submenu with the label "Options" is created even if there is only one single option available, which could be easily placed on the left soft key itself like it was done in the first prototype (see figure 4.4) with the label "Back".

J4ME

J4ME, according to the projects website [7] itself "is a library for quickly building professional J2ME applications". It is an open source project licensed under the Apache 2.0 License, which allows to modify and use the code in any possible way. Since November 2007 and its initial version there were three major new releases.

In this prototype a trimmed-down version of the original J4ME was used. This was due to the fact that J4ME supports GPS but the Nokia 6131 NFC SDK emulator as well as the mobile device itself do not support this. So all classes belonging to the GPS support have been deleted from the J4ME package. Furthermore this also contributes to the goal to offer a lightweight application for the mobile phone, which does not contain any unnecessary code.

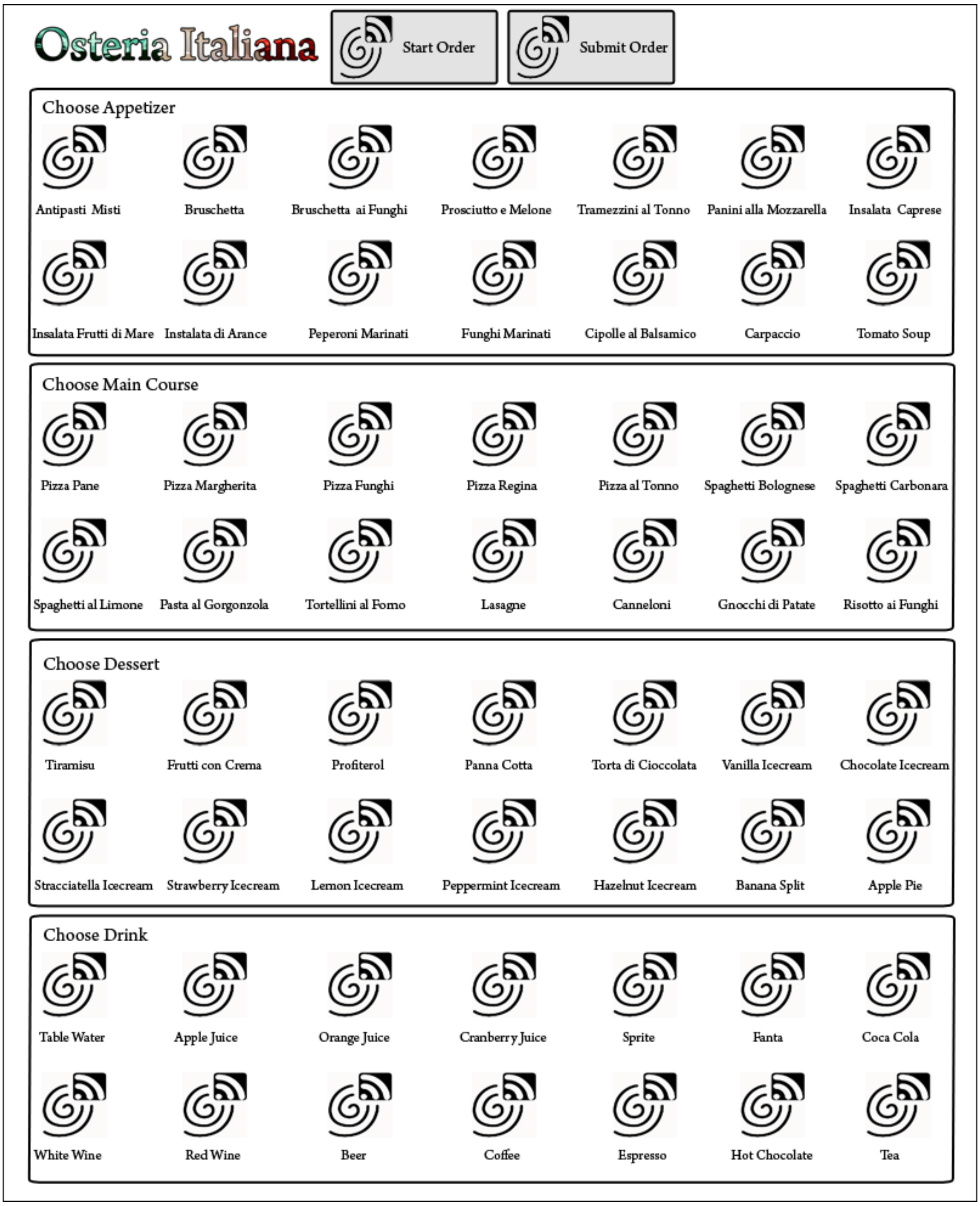

Figure 4.11: NFC-enhanced menu of Multi-Tag Interaction #3 with high interface complexity.

Figure 4.12: The mobile application belonging to Multi-Tag Interaction #3.

Figure 4.13: The Nokia 6131 NFC. One of the rare NFC supporting mobile devices [8].

To use J4ME in one's application, J4ME has to be added to the build path of the particular project.

As already mentioned, J4ME was used for the graphical user interface. Without going into too much technical detail the user interface gets added to the application by initializing the `UIManager` and stating, which screen should be displayed first. Each screen itself is an own java class containing all graphical information about the screen as well as the labels for the soft keys and their functionality.

Another adaption of the basic J4ME framework was necessary because of the radio buttons, which are used in the prototypes for Single-Tag Interaction and Multi-Tag Interaction #1 for the lists to select one's preferred meal from. The standard implementation of radio buttons in J4ME is quite uncommon. The API of J4ME states "Traditionally radio buttons are displayed next to each other in a box. This component forgoes that model to save screen space. Instead the selected option is displayed. If the user pressed a button while the component is highlighted it takes them to a screen, similar to a menu, where the user can choose a different value". This behavior is depicted in figure 4.14.

While there is some eligibility for the special implementation, in this application the usual and already known behavior of radio buttons should be used to avoid confusion and more cognitive work from the user. To achieve that the already implemented checkboxes have been overwritten and have been added the functionality of radio buttons meaning only one at a time can be selected and after selecting a checkbox the previously selected one will be deselected.

Figure 4.14: The rather uncommon but standard behavior of radio buttons using J4ME.

Near Field Communication

Besides having a pleasing and usability friendly user interface the NFC technology [20] has to be incorporated into the application. Having imported `javax.microedition.contactless` the `DiscoveryManager` and a `TargetListener` for each `targetType`, which should be supported, have to be implemented. Furthermore a `NDEFRecordListener` should be added to the code.

The `TargetListener`, after having touched the first tag, calls `targetDetected(TargetProperties[] properties)` and by that a `NDEFTagConnection` is established, which supports the reading and writing of data from and to NFC-tags. Data on NFC-tags is stored as `NDEFMessage`, which itself contains `NDEFRecords`.

Whenever the `NDEFRecordListener` detects a NDEF record the method `recordDetected(NDEFMessage ndefMessage)` is called, which contains instructions on how to handle the tag. E.g. in this prototype the method reads the `payload`, meaning the stored text of the tag, and depending on the text, the application knows whether an appetizer, main course, dessert or drink tag was touched and which exact meal or drink from the corresponding category was chosen and saves the choice.

Furthermore the prototype makes use of the MIDP 2.0 PushRegistry, meaning the application registers to be able to start via the touch of a tag. To register an application the record type format and the record type name has to be provided. At the first start up of the application the user has to accept the registration. Afterwards the application is ready to be started by a NFC-tag, which contains the correct record type and name.

4.2.2 The NFC-Enhanced Poster

Besides the NFC support by the application the NFC-tags itself have to be prepared.

Sticky Mifare Standard 1k NFC-tags (see figure 4.15) were used to enhance the posters, which can be seen in several figures above in section 4.1. Behind every NFC-symbol a tag was hidden.

Figure 4.15: On the left the NFC-symbol indicating that it covers a Mifare Standard 1k NFC-tag as seen on the right.

Basically there are two different tags concerning the content of the tag: start-tags and "normal"-tags.

The start-tag contains information to start the application with the help of the PushRegistry. Each application has a record format and a unique name, which both are stored on the NFC-tag to reference the application.

A "normal"-tag just contains plain text, which is stored in the so-called payload. In these prototypes the convention is to first state the number of the prototype followed by an underscore followed by the category followed by a hyphen and finally the meal that was chosen. E.g. the tag, which refers to the third prototype and is used to order "Pizza Funghi" contains the text "3_maincourse-Pizza Funghi". Furthermore there are submit-tags which contain the keyword "submit" instead of one of the four categories.

4.3 User Study Design

The aim of the user study is to identify to which extent the users enjoy using multi-tag interaction and which prototype offers the best performance concerning execution time, errors and attention shifts.

4.3.1 Experimental Design

Before the conduction of the user study some thoughts concerning the design of the study have to be taken into account.

Hypotheses

Following hypotheses have been established beforehand to be tested, to be confirmed or to be confuted.

- H1: Single-Tag Interaction is slower compared to all designs using multi-tag interaction, causes more errors, but less attention shifts.
- H2: Performance regarding task completion time and number of errors improves from single-tag interaction to multi-tag interaction in the following order: Single-Tag Interaction (just one start-tag), Multi-Tag Interaction #1 (categories as tags), Multi-Tag Interaction #2 (the wizard), Multi-Tag Interaction #3 (all steps were achieved by interaction with the poster), but the number of attention shifts increases.
- H3: The differences between the performances of these designs are emphasized for tasks with more complex interfaces and complex tasks.
- H4: Guided interaction is less effective than arbitrary interaction design.
- H5: The usage of the PushRegistry distinctly improves usability of the application.

Independent Variables

During the user study three independent variables are tested: design, interface complexity and task complexity.

The independent variable design has four levels, meaning the different prototypes, Single-Tag Interaction, Multi-Tag Interaction #1, Multi-Tag Interaction #2 and Multi-Tag Interaction #3, as depicted in section 4.1.

Interface complexity has two levels, the short list containing seven items to choose from and the long list containing fourteen items to choose from. Interface complexity was implemented for all four prototypes. The first two prototypes, Single-Tag Interaction and Multi-Tag Interaction #1, handle those items as lists on the mobile device. Depending on the complexity, the list cannot be displayed on one single screen but the user has to scroll to see all items. Concerning Multi-Tag Interaction #2 and Multi-Tag Interaction #3 all items are placed on the paper menu, which is put in front of the user. The menu with low interface complexity, containing seven items, is DIN A3 sized while the menu with the high interface complexity, containing fourteen items, is DIN A2 sized.

Task complexity consists of two levels, the simple task execution and the task execution with two changes. Depending on the interface complexity the subjects are asked to choose different meals.

The following four task descriptions are handed to the subjects to accomplish.

1. Low interface complexity and low task complexity:

   You are at the Italian restaurant "Osteria Italiana" and you want to use your mobile phone to order your food and drink.

   You are ordering:

   - *Appetizer: Panini alla Mozarella*
   - *Main course: Pizza Funghi*
   - *Dessert: Profiterol*
   - *Drink: Orange Juice*

2. Low interface complexity and high task complexity:

   You are at the Italian restaurant "Osteria Italiana" and you want to use your mobile phone to order your food and drink.

   You are ordering:

   - *Appetizer: Carpaccio*
   - *Main course: Canneloni*
   - *Dessert: Apple Pie*
   - *Drink: Hot Chocolate*

3. High interface complexity and low task complexity:

   You are at the Italian restaurant "Osteria Italiana" and you want to use your mobile phone to order your food and drink.

   You are ordering:

   - *Appetizer: Panini alla Mozarella*
   - *Main course: Pizza Funghi*
   - *Dessert: Profiterol*
   - *Drink: Orange Juice*

   Before you submit your order you decide that you would rather prefer Spaghetti Bolognese instead of Pizza Funghi as main course and Tiramisu instead of Profiterol as dessert. You are changing your order accordingly.

4. High interface complexity and high task complexity:

   You are at the Italian restaurant "Osteria Italiana" and you want to use your mobile phone to order your food and drink.

   You are ordering:

   - *Appetizer: Carpaccio*
   - *Main course: Canneloni*
   - *Dessert: Apple Pie*
   - *Drink: Hot Chocolate*

   Before you submit your order you decide that you would rather prefer Risotto ai Funghi instead of Canneloni as main course and Hazelnut Icecream instead of Apple Pie as dessert. You are changing your order accordingly.

Dependent Variables

Furthermore the following dependent variables are measured: task execution time, number and kind of errors and number of attention shifts.

To measure task execution time a timer is implemented in all applications, which records the time in milliseconds from the start of the application to the submission of the order. The execution time for each task by each user is stored in the RecordStore of the midlet and therefore can easily be read out by the investigator. Additionally the time, which is needed to start Multi-Tag Interaction #2, the only prototype that is not evoked with the help of the PushRegistry but by navigation through the mobile phones device, has to be measured separately. Each participant is asked for the permission to record the user study on tape. The time to open the application is stopped afterwards via video analysis and added to the value, which is recorded by the application itself.

The number and kind of errors are already documented by the investigator during conduction of the study. With the help of video analysis the already existing notes are adjusted and refined.

Like the error analysis the analysis of the number of attention shifts is done via video analysis. Each macro attention shift between the mobile device and the tag-enhanced menu is counted.

Latin Square

The user study is conducted with the help of a within-subjects respectively repeated measures experimental design [10]. This means all subjects will perform every condition. One big benefit of repeated measure is that one eliminates random noise, which could arise if using different people for the different conditions, who of course have different skills. This could also reduce the variation in the results and only show variation that is directly caused by the change of the independent variables. This makes the repeated measure design more sensitive, meaning that effects, depending on the independent variables, will be more likely to be detected.

Anyway there are also problems occurring with repeated measure designs, which should not be ignored. To begin with, the subjects might answer slightly different even if the manipulations of the independent variables might not affect them. To overcome this problem the main focus of the evaluation is set on quantitative data, which has been recorded like execution time or errors. But besides that of course also "soft data" in form of a questionnaire, which asks for the rating of the users on several questions is collected. Furthermore to avoid learning effects or other side effects like weariness, the different conditions were counterbalanced using a latin square design. The big advantage of the latin square design, in contrast to straight forward counterbalancing, is that one significantly reduces the number of participants, which are needed to be relatively sure that no ordering effects do affect the results. While designing the latin square for this experiment one has to keep in mind that in this case one has to deal with a multivariate design consisting of three independent variables.

The two independent variables, interface complexity and task complexity, both only have to levels. But by combining those two independent variables one gets four different tasks as already depicted before: Low interface complexity and low task complexity, low interface complexity and high task complexity, high interface complexity and low task complexity and high interface complexity and high task complexity. The third independent variable, design, contains four levels itself: Single-Tag Interaction, Multi-Tag Interaction #1, Multi-Tag Interaction #2 and Multi-Tag Interaction #3. Therefore two latin square designs, consisting each of four levels, have to be combined in this case. Figure 4.16 depicts the latin square for the design, whereas figure 4.17 shows the latin square for the combination of interface and task complexity.

Order of Design			
Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2	Multi-Tag Interaction #3
Multi-Tag Interaction #1	Multi-Tag Interaction #3	Single-Tag Interaction	Multi-Tag Interaction #2
Multi-Tag Interaction #3	Multi-Tag Interaction #2	Multi-Tag Interaction #1	Single-Tag Interaction
Multi-Tag Interaction #2	Single-Tag Interaction	Multi-Tag Interaction #3	Multi-Tag Interaction #1

Figure 4.16: Latin square for the independent variable design.

Order of the Combination of Interface and Task Complexity			
Low Interface and Low Task Complexity	Low Interface and High Task Complexity	High Interface and Low Task Complexity	High Interface and High Task Complexity
Low Interface and High Task Complexity	High Interface and High Task Complexity	Low Interface and Low Task Complexity	High Interface and Low Task Complexity
High Interface and High Task Complexity	High Interface and Low Task Complexity	Low Interface and High Task Complexity	Low Interface and Low Task Complexity
High Interface and Low Task Complexity	Low Interface and Low Task Complexity	High Interface and High Task Complexity	Low Interface and High Task Complexity

Figure 4.17: Latin square for the combination of the independent variables interface complexity and task complexity.

Combining those two latin squares no participant will get the exact same order as another participant. Figure 4.18 shows the actual list of tasks for the first participant. In this case the participant starts with Single-Tag Interaction and carries out all four tasks, low interface and low task complexity, low interface and high task complexity and so on with this prototype. Afterwards the subject has to carry out all four tasks with the prototype for Multi-Tag Interaction #1.

	#1	#2	#3	#4
Design	Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2	Multi-Tag Interaction #3
Interface and Task Complexity	Low Interface and Low Task Complexity	Low Interface and High Task Complexity	High Interface and High Task Complexity	High Interface and Low Task Complexity
Interface and Task Complexity	Low Interface and High Task Complexity	High Interface and High Task Complexity	High Interface and Low Task Complexity	Low Interface and Low Task Complexity
Interface and Task Complexity	High Interface and Low Task Complexity	Low Interface and Low Task Complexity	Low Interface and High Task Complexity	High Interface and High Task Complexity
Interface and Task Complexity	High Interface and High Task Complexity	High Interface and Low Task Complexity	Low Interface and Low Task Complexity	Low Interface and High Task Complexity

Figure 4.18: Table of tasks for the first participant.

4.3.2 Conducting the User Study

The actual study is conducted using sixteen participants. This number of participants is derived from the latin square design. This way each possible order of design, interface complexity and task complexity is tested.

After having been given basic instructions about the user study and getting the permission to record the task on video the subject is asked to fill out a questionnaire (see appendix) about their demographics and their technical background and technical knowledge.

Afterwards all four prototypes are presented to the user one after another. The order depends on the latin square but for each prototype the general procedure is the same. The subject gets a short introduction to the prototype. At first he is introduced to the overall usage of NFC-tags and the mobile device. Moreover a trial order is executed so the subject knows every interaction, which he will need to perform during the given tasks like how to order, how to change one's order and how to submit it. Before going on with the execution of the tasks the subject is asked whether he understood how the prototype worked. This is done to simulate a user, who is already experienced with the technology itself and the prototype. Afterwards the four tasks depending on interface and task complexity are executed by the subject.

Having finished all four tasks the user is asked to answer the standardized IBM "Computer System Usability Questionnaire" [24]. The questionnaire is configured to offer a Likert scale with seven levels to answer each question. Furthermore the option to leave comments for each question is given and in the end there is the possibility to state up to three positive and three negative aspects of the previously used prototype (see appendix).

This procedure will be repeated until all four prototypes are tested by the subject. Afterwards the user is asked to fill out the closing questionnaire (see appendix), which asks him to compare the four presented prototypes, which interaction he prefers to carry out with the mobile interface and which ones on the tag-enhanced poster and which overall problems occurred while ordering the food with the help of the four prototypes.

Figure 4.19 gives some impressions of the conduction of the user study.

Figure 4.19: Conducting the user study. Subject scrolling through the lists on the mobile device, interacting with the tag-enhanced poster, using the PushRegistry to launch the application and filling out the IBM questionnaire.

4.4 Evaluation of the User Study

Having collected all this data, it was evaluated using SPSS [9]. Especially all data concerning the dependent variables execution time, attention shifts and errors were given a closer look. To analyze the normal distribution the Kolmogorov-Smirnov was used. Furthermore a repeated measure Anova for several independent variables was applied.

4.4.1 Demographics and Technical Background

At first some information on the demographics of the subjects. All in all sixteen people were tested, nine male and seven female. The average age is 25,1 and most of the participants have a background in computer science (informatics, media informatics, bio informatics) but also one student of ethnology and one student of biochemistry took part.

All participants own a mobile phone for an average of 7,9 years. They rated their experience with mobile devices on a Likert scale from one to five with 3,8. Their overall technical knowledge was rated very high with 4,5. This can be explained with the fact that nearly all of the participants work in the field of computer science. Most of the participants (14) have heard of the RFID/NFC technology but only four have already taken part in a user study concerning this technology.

4.4.2 Attention Shifts

Attention shifts are counted with the help of video analysis. Only macro attention shifts between the mobile device and the tag-enhanced poster are counted.

The Kolmogorov-Smirnov test can only be applied to the attention shift data of Multi-Tag Interaction #2 and Multi-Tag Interaction #3. This is due to the fact that for Single-Tag Interaction and Multi-Tag Interaction #1 the number of attention shifts is constant throughout all participants, which will be explained a little bit later.

Looking at the results of the Kolmogorov-Smirnov test for Multi-Tag Interaction #2 and Multi-Tag Interaction #3, the Tests of Normality show that all data is highly significant, meaning significance is below 0,05, and therefore the distribution is not normal. This is explained with the fact that the interaction design already provides a rather strong guidance for the user, which results in a very similar number of attention shifts throughout all participants.

Taking a closer look on Mauchly's Test of Sphericity one can only see that one cannot say anything about the significance. This is due to the fact, that Mauchly's Test of Sphericity can only be applied to variables with more than two levels. Actually the variable design offers four levels, but two of them show exactly the same number of attention shifts for each participants, and therefore the standard deviation is zero, which only leaves two levels to look at, which, as stated, is too less to perform the test.

Figure 4.20 shows the mean and standard deviation for every task and every prototype.

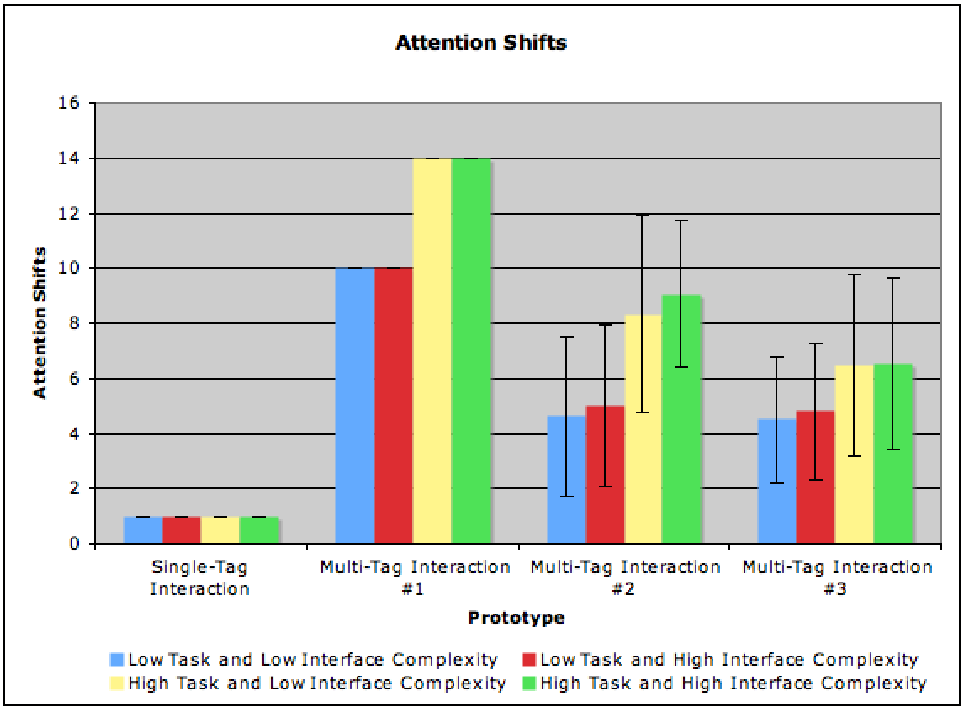

Figure 4.20: The mean and standard deviation of the attention shifts for all four prototypes and all scenarios.

As one can see, using Single-Tag Interaction, only one attention shift (for all four scenarios: m=1,00; sd=0,00) is executed by all participants. This is not surprising since there is only one tag and after touching this tag the application is launched and all further interaction is executed only on the mobile device itself. This does not change no matter if the task complexity - just a "normal order" or changes of the choices in the end - or the interface complexity - seven our fourteen meals to choose from - is varied.

Using Multi-Tag Interaction #1 there is also a constant number of attention shifts comparing the attention shifts of different subjects. Interface complexity also does not influence the number of attention shifts since the difference is just a longer list shown on the mobile device itself. But there is a difference concerning task complexity. With low task complexity the user has to go back and forth between the mobile device and the tag-enhanced poster for ten times (m=10,00; sd=0,00) to touch the start-, category-, or submit-tag. Dealing with high task complexity, the subject is asked to change and correct two categories, main course and dessert, this results in four additional attention shifts resulting in a total of fourteen attention shifts (m=14,00, sd=0,00) for both cases with high task complexity because the user has to touch two categories again on the tag-enhanced poster.

In contrast to the previously mentioned two prototypes Multi-Tag Interaction #2 does not provide a constant number of attention shifts. This is due to the fact that the user does not necessarily have to look at the mobile device between the selection of meals from each category. This can be done to check whether touching the NFC-tag has worked correctly, but many subjects did not do this after each selection because they trusted the haptic feedback, also known as vibration, while touching the tag. Anyway it can be observed that the number of attention shifts is not much affected by the interface complexity but by the task complexity. This is also confirmed by the Anova test of within-subjects. The independent variable design and task complexity is significant (both p<.001) whereas interface complexity is not significant. Attention shifts for low task complexity combined with low interface complexity has a mean of 4,62 and a standard deviation of 2,89. Very similar is low task complexity combined with high interface complexity with a mean of 5,00 and a standard deviation of 2,92. In contrast high task complexity combined with low interface complexity has a mean of 8,31 and a standard deviation of 3,57 and finally high task complexity combined with high interface complexity has a mean of 9,06 and a standard deviation of 2,67.

The last prototype Multi-Tag Interaction #3 shows a similar number of attention shifts as Multi-Tag Interaction #2. They are even a little bit lower than the ones of the previous prototype considering the scenarios with high task complexity. At first this is surprising because Multi-Tag Interaction #3 adds two additional tags, the start- and the submit-tag, to the tag enhanced poster, but the smaller number of attention shifts is due to the fact that correction can be done more easily by just touching another tag at any point instead of pressing the left soft key labeled "Correction" on the mobile device to switch to the correction mode. Low task complexity combined with low interface complexity has a mean of 4,50 and a standard deviation of 2,28. Low task complexity combined with high interface complexity has a mean of 4,81 and a standard deviation of 2,48. In contrast high task complexity combined with low interface complexity has a mean of 6,50 and a standard deviation of 3,30 and high task complexity combined with high interface complexity has a mean of 6,56 and a standard deviation of 3,11.

At last one is having a closer look on the Pairwise Comparison with Bonferroni Correction of the Anova. Pairwise Comparison of design shows that all Pairwise Comparisons of all levels are significant (p<.000) but one. Changing between Multi-Tag Interaction #2 and Multi-Tag Interaction #3, there cannot be any significant influence be detected. Comparing interface complexity, there is no significant change either. But in contrast the comparison of task complexity shows a significant influence (p<.001) on the number of attention shifts.

Anyway, especially using Multi-Tag Interaction #2 and Multi-Tag Interaction #3, the number of attention shifts might be a bit higher in a real life scenario than in the user study. Being in a user study the user knows that he will not actually get the meal and therefore there are no consequences in selecting the wrong meal hence the motivation to check the correctness of the order is lower than in a real life situation.

4.4.3 Errors

When looking at the numbers of errors depicted in figure 4.21 one might realize that only very few errors occurred. This is probably due to the fact that all subjects got an explanation for every prototype and all its functionality along side a test run for each prototype.

The really small number of errors is also the explanation for the results of the Kolmogorov-Smirnov test, which stated all scenarios and prototype combinations to be highly significant and therefore not normally distributed.

Taking a look at sphericity with the help of Mauchly's Test one can see that all independent variables and all combinations of independent variables where Mauchly's Test can be applied to - task complexity and interface complexity both only have two levels, therefore Mauchly's Test cannot be applied - are highly significant. Consequently the condition of sphericity is not met and some conditions are more related than others.

While using Single-Tag Interaction, only two errors occurred throughout all scenarios. They were related to the usage of the radio buttons. As already stated in 4.2.1 the radio buttons actually are remodeled checkboxes due to the lack of real radio buttons in the J4ME framework. Using

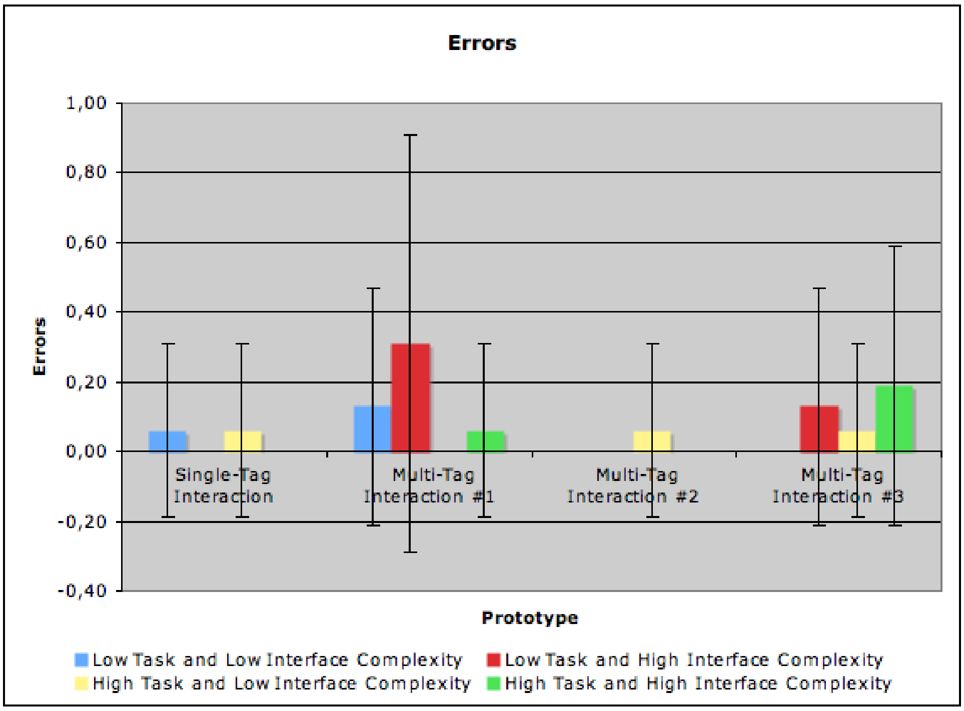

Figure 4.21: The mean and standard deviation of the errors for all four prototypes and all scenarios.

the arrow keys one can move the highlight up and down. Having highlighted the radio button respectively the remodeled checkbox, which belongs to the desired meal one had to hit the button in the middle of the arrow keys. This last step turned out to be a bit of a problem to some users because they moved the highlight, but in the end forgot to actually confirm the selection. This error was made once in scenario one (low task and interface complexity) and once in scenario three (high task and low interface complexity) but this can be assumed to be coincidental. Anyhow this leads to the following means and standard derivations. Low task and low interface complexity as well as high task and low interface complexity with m=0,06 and sd=0,25 while low task and high interface complexity and high task and high interface complexity had m=0,00 and sd=0,00 because there did not occur any errors at all.

Considering Multi-Tag Interaction #1 the problem with the radio buttons appeared four times. Furthermore problems handling the NFC-tags occurred. One person got haptic feedback from the mobile device but anyway the tag was not read correctly. It is assumed that the contact between mobile device and NFC-tag was too short and therefore it could not be read properly. The same subject happened to read another tag than the one intended to read. Furthermore another subject forgot all about the start-tag although of course he was told about it beforehand and actually did already use it in a test run. He therefore tried to browse through the menu of the mobile device to start the application. Anyway, as well as with Single-Tag Interaction one can assume that this are general problems of Multi-Tag Interaction #1 and do not depend on the task or interface complexity. This lead to the following means and standard deviations for the prototype Multi-Tag Interaction #1: low task and low interface complexity m=0,13, sd=0,34; low task and high interface complexity m=0,31, sd=0,60; high task and low interface complexity m=0,00, sd=0,00; high task and high interface complexity m=0,06, sd=0,25.

Using Multi-Tag Interaction #2 only one error occurred. Once again the mobile device gave haptic feedback without having read the content of the NFC-tag properly. Consequently the means and standard deviations are the same for low task and low interface complexity, low task and high interface complexity as well as high task and high interface complexity with m=0,00 and sd=0,00.

The only error occurred during the high task and low interface complexity scenario resulting in m=0,06 and sd=0,25. But once again it is coincidence that the error occurred during this scenario.

Testing Multi-Tag Interaction #3 some already known errors occurred. One user did not hold the mobile device close enough to the NFC-tag to be read. Once again the mobile device gave haptic feedback but did not read the tag properly. Other users forgot all about the start-tag and wanted to start with the help of the mobile device's menu. Furthermore "submit" was expected to be on the mobile device as soft key option instead of the submit tag. But the biggest problem was the placement of the actual tag behind the boxes saying "Start Order" and "Submit Order" as shown in figure 4.22. Users often touched the middle of each box to start or submit, which sometimes lead to the problem that no tag at all was read because the tag was placed directly under the NFC-symbol. This did not appear to be intuitive for the users. The means and standard deviations are as followed: low task and low interface complexity m=0,00, sd=0,00; low task and high interface complexity m=0,13, sd=0,34; high task and low interface complexity m=0,06, sd=0,25; high task and high interface complexity m=0,19, sd=0,40.

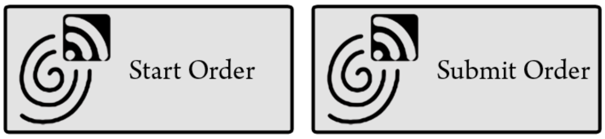

Figure 4.22: The start- and submit-tag of Multi-Tag Interaction #3. The tag is placed behind the NFC-symbol.

Having a look at the Within-Subjects Effects the combination of interaction and task complexity is the only significant value.

Last but not least looking at the Pairwise Comparison there is one single significance concerning the comparison of Single-Tag Interaction and Multi-Tag Interaction #3. Consequently interchanging those two designs seems to make a significant difference. Taking a closer look on Pairwise Comparison of task and interface complexity no significance can be detected.

Anyhow these results should not be taken for granted due to the already mentioned reason that all in all only very few errors occurred and therefore the data is not really reliable or that meaningful.

4.4.4 Execution Time

The execution time was recorded by the mobile application itself, from touching the start-tag until submitting the order. The only exception was Multi-Tag Interaction #2, which did not offer a start-tag. Therefore, with the help of video analysis, the time the user needed to start the application with the help of the mobile device's menu was stopped afterwards and added to time, which was recorded by the mobile application while touching the tags and ordering the food according to the scenarios. This of course leads to some inaccuracy concerning the time measurement of Multi-Tag Interaction #2.

Of course the Kolmogorov-Smirnov test was also applied to the execution times. For most combinations of design, task and interface complexity the test did not show any significance and therefore most execution times are normally distributed. But anyhow Multi-Tag Interaction #1 with low task and high interface complexity, Multi-Tag Interaction #2 with high task complexity and low interface complexity and Multi-Tag Interaction #3 with low task complexity and low interface complexity are significant and therefore they are not normally distributed.

Corresponding to the previously analyzed independent variables Mauchly's Test was applied to the data. One significance can be discovered for the combination of design and interface complexity. All other values did not offer significance and therefore the conditions of sphericity are met for them.

Figure 4.23 shows the means and standard deviations for execution time.

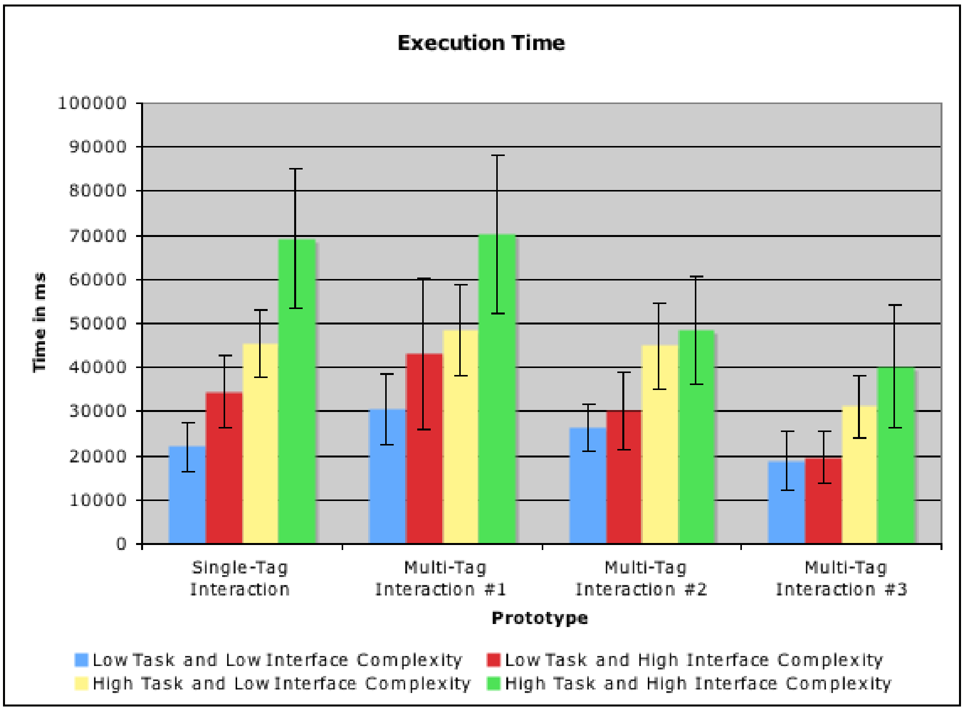

Figure 4.23: The mean and standard deviation of the execution time for all four prototypes and all scenarios.

Looking at each four means of each of the four levels of interface complexity one can state that low task and low interface complexity was the fastest, followed by low task and high interface complexity, followed by high task and low interface complexity and as slowest scenario high task and high interface complexity, which is not surprising.

The means and standard deviations concerning execution time (in ms) for Single-Tag Interaction are as follows: low task and low interface complexity with m=22009,94 and sd=5435,82, low task and high interface complexity with m=34491,19 and sd=8094,85, high task and low interface complexity with m=45342,44 and sd=7588,65, and high task and high interface complexity with m=69235,50 and sd=15790,62.

The means of the second prototype, Multi-Tag Interaction #1, are the highest making it slightly slower than Single-Tag Interaction. Low task and low interface complexity with m=30619,78 and sd=8058,32, low task and high interface complexity with m=43185,69 and sd=17289,33, high task and low interface complexity with m=48442,12 and sd=10236,52, and high task and high interface complexity with m=70221,94 and sd=17856,87.

As the diagram (see figure 4.23) already shows, and the following numbers prove, the first two prototypes are considerably slower. This is probably mostly due to the long lists of radio buttons the user has to scroll through to find the meal or drink he wants to order. The comparably many attention shifts, which are necessary when using Multi-Tag Interaction #1, are probably responsible for the fact that it is even a bit slower than Single-Tag Interaction.

Multi-Tag Interaction #2 is clearly faster than the previous two. Low task and low interface complexity with m=26329,44 and sd=5453,75, low task and high interface complexity with m=30171,62 and sd=8883,16, high task and low interface complexity with m=44943,88 and sd=9701,23, and high task and high interface complexity with m=48464,63 and sd=12188,11.

The last level for design is Multi-Tag Interaction #3 and it is also the fastest one. Compared to Multi-Tag Interaction #2 this can be explained firstly by the fact that Multi-Tag Interaction #3 is started using a start-tag, which is considered to be faster than the mobile device's menu and secondly the correction of already made choices is easier and can be performed at any time in contrast to the correction mode of Multi-Tag Interaction #2, which can only be accessed after having selected all four meals and is started by pressing the left soft key labeled "Correction". The mean and standard deviations are as follows: Low task and low interface complexity with m=18882,25 and sd=6784,23, low task and high interface complexity with m=19636,69 and sd=5938,86, high task and low interface complexity with m=31143,81 and sd=7059,02, and high task and high interface complexity with m=40223,31 and sd=14070,90.

Having a look at the Within-Subjects Effects all independent variables and all combinations of independent variables are significant except the total combination of design, task, and interface complexity. Consequently this states a strong effect concerning changes of all independent variables.

Finally Pairwise Comparison was analyzed. Except the Pairwise Comparison of Single-Tag Interaction and Multi-Tag Interaction #1, all prototypes show a high significance when being compared. Consequently interchanging the prototypes - once again of course without the interchanging of Single-Tag Interaction and Multi-Tag Interaction #1 - highly affects the results of execution time. It is exactly the same when looking at task complexity and at interface complexity. Both are highly significant ($p<.001$) and therefore do have a strong effect on the execution time.

Keystroke-Level Model

Besides the data, which was measured in the user study, the execution time for all prototypes and each scenario was calculated with the help of the Keystroke-Level Model. The original Keystroke-Level Model is designed for desktop applications and helps the developer to estimate the total execution time for a task without having a working prototype to test it. In this case the adaption of the Keystroke-Level Model for mobile devices [17] was used to achieve that. Although there are several other adaptions of the Keystroke-Level Model for mobile devices most of them focus on traditional input methods with the help of the keypad whereas [17] also includes the interaction with visual markers, NFC-tags etc., which is essential in this case.

While adapting the model to the special needs of advanced mobile phone interaction, several new operators have been included whereas others have been adapted and some have been taken over without any changes.

Applying the Keystroke-Level Model to the prototypes and scenarios of this user study the operator "initial act" was ignored because the measurement of each task started after the initial act, which consists of the start of the mobile application.

All in all this leads to the following results.

Looking at the values for Single-Tag Interaction, as depicted in figure 4.24, one can see that most of the calculated times are quite close to the measured times. The only quite noticeable divergency can be noted concerning the last scenario with high task and high interface complexity. The value, which was calculated is 51,48s, whereas the measured value is 69,23s, which is 17 seconds more than expected although no errors did occur during the execution of the tasks. At that point no explanation for this can be given.

Comparing the calculated and measured values for Multi-Tag Interaction #1, as shown in figure 4.25, one realizes that the calculated values are much higher than the measured ones. At this point one cannot clearly say what the reasons for this phenomena are, but one possible explanation is the fact that two macro attention shifts are needed to select a category. The rules of KLM indicate to add a mental act before every macro attention shift. Given the fact that the users followed a strict given task, which they have in written form in front of them, this might not be appropriate and lead to calculated times, which are too long.

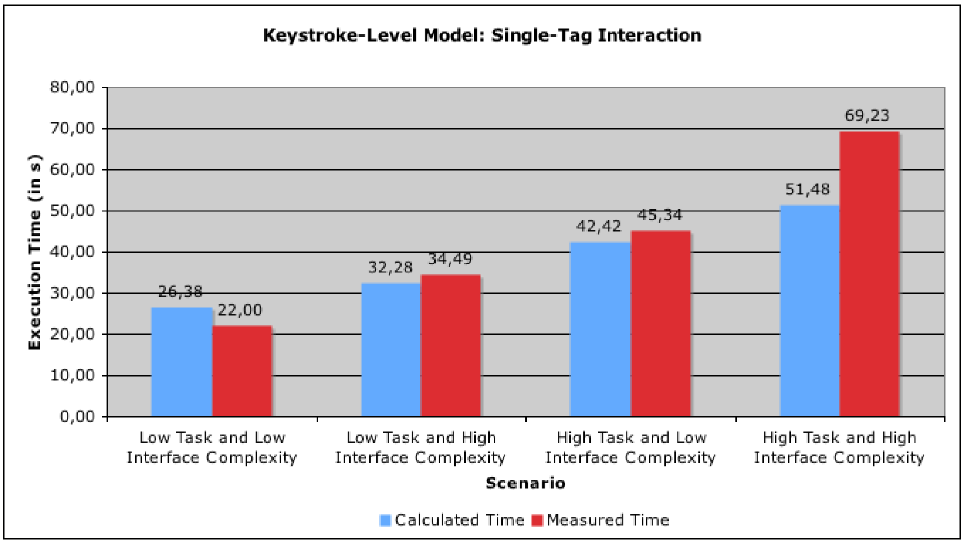

Figure 4.24: The calculated and measured times for Single-Tag Interaction.

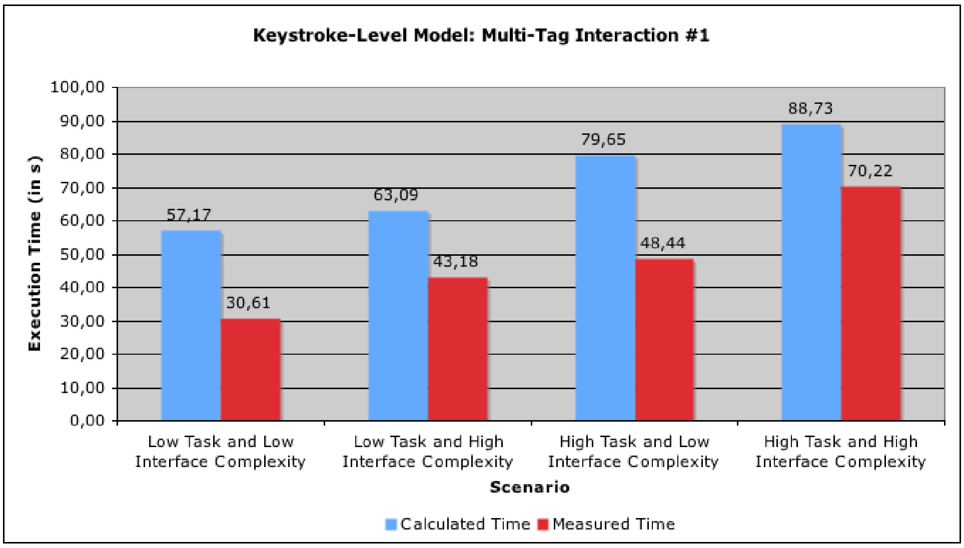

Figure 4.25: The calculated and measured times for Multi-Tag Interaction #1.

Like the values for Multi-Tag Interaction #1 the calculated values for Multi-Tag Interaction #2, as depicted in figure 4.26, do differ quite a lot from the actual measured ones. But this can easily be explained, because the calculated numbers are based on the assumption that the user, after having touched a tag and before touching the next one, looks on the mobile device's display to check whether the selection via the NFC-tag worked properly. During the study one could observe that this was not the case and that users only sporadically check the mobile device and therefore the number of macro attention shifts decreases. Applying the mean number of attention shifts to the Keystroke-Level Model's calculation, the numbers are quite similar.

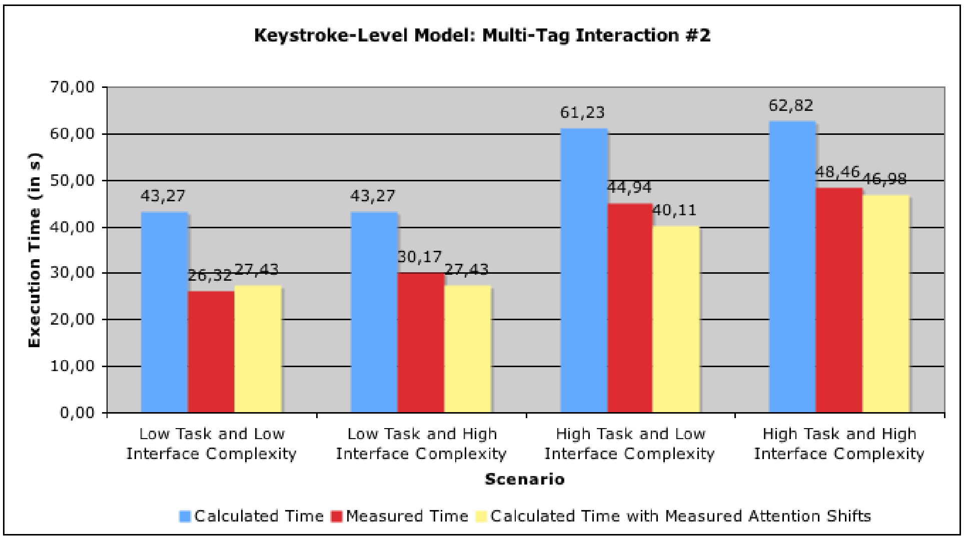

Figure 4.26: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #2.

Execution times and the calculated values for Multi-Tag Interaction #3, shown in figure 4.27, behave similar like the values of Multi-Tag Interaction #2. Once the number of attention shifts is reduced to the number of attention shifts, which actually occurred during the execution, the numbers match very well. Only the numbers for the last scenario with high task and high interface complexity do not fit that perfectly. This can be explained with the fact that three errors were made during the execution of this scenario, which is a rather high number of errors compared to the errors, which have been made during the other scenarios.

Furthermore one has to keep in mind that high interface complexity, meaning the bigger posters with the doubled number of NFC-tags, cannot be taken into account with the Keystroke-Level Model, which affects Multi-Tag Interaction #2 and Multi-Tag Interaction #3. Surprisingly this cannot be observed when looking at the numbers due to the fact that the measured execution times of the two levels of interface complexity do not differ that much.

4.4.5 Verifying the Hypotheses

In section 4.3.1, five hypotheses focusing on the three dependent variables have been established.

The first hypotheses cannot be completely verified. Indeed Single-Tag Interaction causes less attention shifts than all Multi-Tag Interaction designs, but even if only slightly, Multi-Tag Interaction #1 is slower concerning the execution time. As already mentioned, generally very few errors occurred and some of them are not really only a problem of the specific prototype. Anyway, only Multi-Tag Interaction #2 caused less errors than Single-Tag Interaction.

Consequently the second hypotheses cannot be completely verified either. Multi-Tag Interaction #1 caused far more attention shifts than Multi-Tag Interaction #2 and #3. Besides the slightly

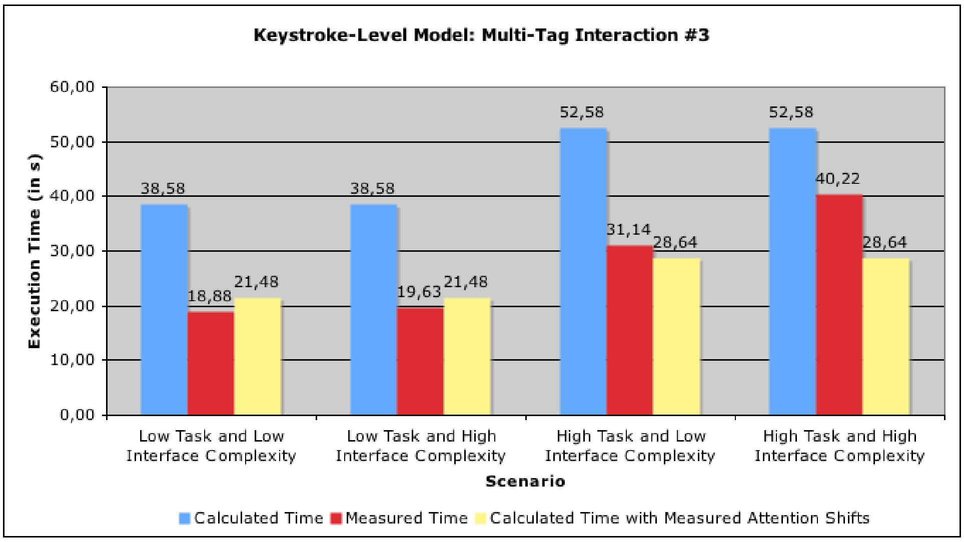

Figure 4.27: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #3.

longer execution time for Multi-Tag Interaction #1, execution time really was fastest for Multi-Tag Interaction #3. Errors are very diverse distributed on all prototypes.

Hypotheses number three can be confirmed. Performance increased when increasing task or interface complexity.

Single-Tag Interaction and especially Multi-Tag Interaction #2 gave the user a strong guidance considering the order of the execution. Anyway, Multi-Tag Interaction #1, which offered freedom considering the order of choices was the least effective.

Using the menu instead of the PushRegistry in Multi-Tag Interaction #2 did not result in bad execution times or more errors. Considering the likability of the PushRegistry the following section, dealing with qualitative data given by the user, will shed more light on this.

4.4.6 User Feedback

As already mentioned, after the user completed all four scenarios with one prototype, he was asked to fill out the "Computer System Usability Questionnaire" [24]. Furthermore after the completion of the whole user study the user was asked to fill out a questionnaire, which asked for the comparison of the four prototypes. Besides the already presented measured data for attention shifts, errors and execution time, this provided some general feedback about the user's acceptance and satisfaction of the presented interfaces and interaction designs.

Standardized IBM "Computer System Usability Questionnaire"

The standardized IBM "Computer System Usability Questionnaire" [24] consists of nineteen questions, which can be answered by rating the prototype on a Likert scale with seven levels ranging from "-3" to "+3" and furthermore one option, which can be selected if the user comes to the conclusion that the question is not applicable to the beforehand tested prototype. Besides that, the user can leave a comment to every question with additional thoughts about the question concerning the prototype. At the end there is also some space to leave additional positive as well as negative thoughts on the prototype.

Figure 4.28 and figure 4.29 show the results of all nineteen questions for each prototype. Just by throwing a glance at the figures one can see that obviously the highest ratings for nearly all questions were given to Multi-Tag Interaction #3. Considering Single-Tag Interaction the difference to Multi-Tag Interaction #1 and Multi-Tag Interaction #2 is not that big but in most cases Single-Tag Interaction has the lowest rating. In the following the results will be stated more detailed.

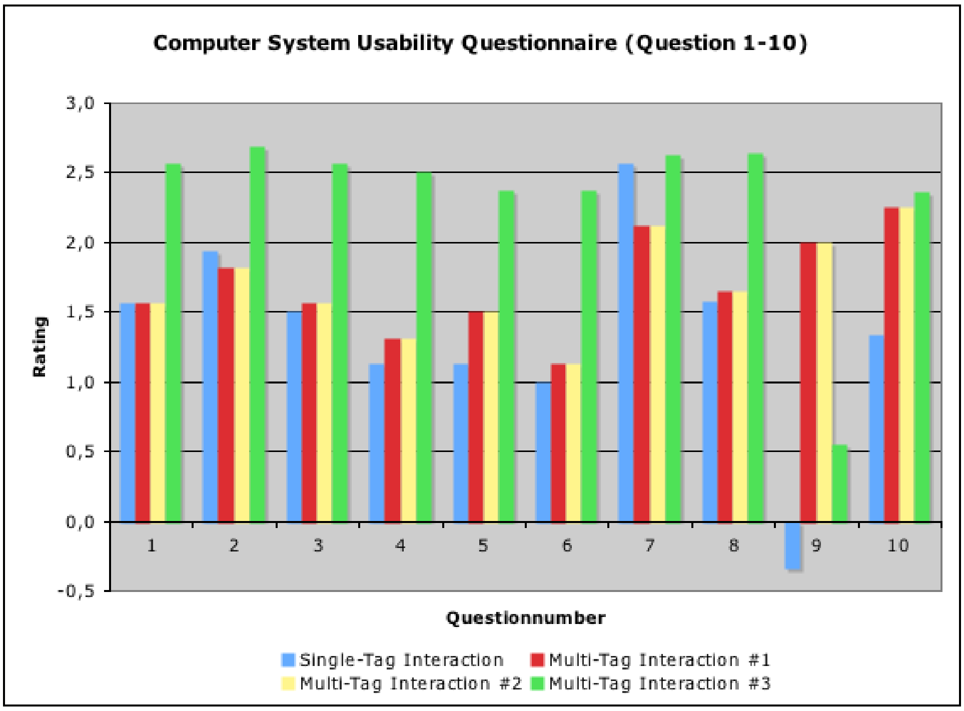

Figure 4.28: The results of question 1 to 10 of the standardized IBM "Computer System Usability Questionnaire".

Concerning the overall satisfaction about the easy usage of the prototype, the highest rated one was Multi-Tag Interaction #3 with a score of 2,6 in contrast to 1,6, which was the rating for all three other ones.

Asking how simple the usage of the prototype was, Multi-Tag Interaction #3 once again scored the highest rating with 2,7, the second best was Single-Tag Interaction with 1,9 followed closely by Multi-Tag Interaction #1 and Multi-Tag Interaction #2 with 1,8.

The rating for the question how effectively one can complete the work using this prototype once again was highest for Multi-Tag Interaction #3 with 2,6. Single-Tag Interaction scored 1,5 and Multi-Tag Interaction #1 and Multi-Tag Interaction #2 both 1,6.

Quickness was rated with 2,5 for Multi-Tag Interaction #3. The other three prototypes are far behind with 1,1 for Single-Tag Interaction and 1,3 for Multi-Tag Interaction #1 and Multi-Tag Interaction #2.

Efficiency gives nearly the same ratings as quickness. Multi-Tag Interaction #3 has the highest rating with 2,4, Single-Tag Interaction scores 1,1 and Multi-Tag Interaction #1 and Multi-Tag Interaction #2 both 1,5.

The users only feel really comfortable with Multi-Tag Interaction #3, which they rated with 2,4, while Single-Tag Interaction scored 1,0 and the other both, Multi-Tag Interaction #1 and Multi-Tag Interaction #2, scored 1,1.

Asking the users how easy it is to learn the usage of the prototypes all four prototypes did have quite good ratings. Anyway once again Multi-Tag Interaction #3 got the highest score with 2,6 but is followed very closely by Single-Tag Interaction which also scores 2,6. Multi-Tag Interaction #1 and Multi-Tag Interaction #2 both were rated with 2,1.

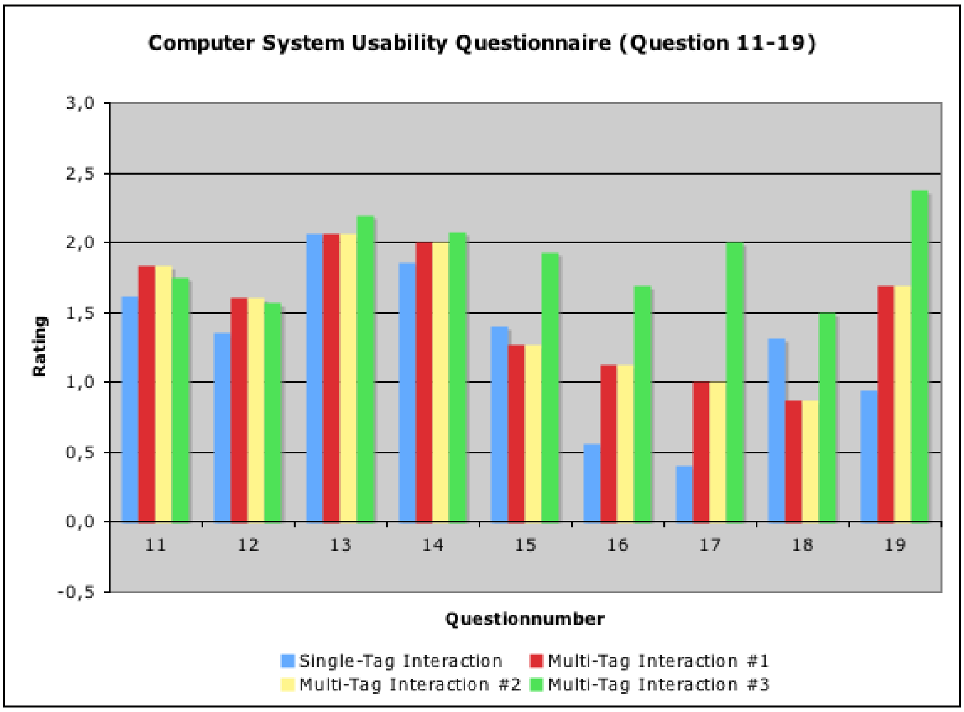

Figure 4.29: The results of question 11 to 19 of the standardized IBM "Computer System Usability Questionnaire".

The eighth question was whether the user believes that he became productive quickly using the prototype. Again Multi-Tag Interaction #3 did score much higher than the other three with 2,6, whereas all other prototypes were rated with 1,6.

Being asked about error messages and whether they are clear and do help fixing the problem many users chose the option "not applicable" because as already stated above, not many errors occurred during the user study and therefore many subjects never saw any error messages. Single-Tag Interaction is designed the way that actually no errors, like forgetting to select a meal, can happen. Other errors, like problems touching a tag, cannot be caught by the application anyway in any prototype. This led to the rating of -0,3. Also Multi-Tag Interaction #3 for once got a bad rating with 0,6. Actually only one error can be made using Multi-Tag Interaction #3, which is to select not all four courses as requested in the user study. But this request of course is obsolete in a real life situation. Multi-Tag Interaction #1 and Multi-Tag Interaction #2 both were rated quite well with 2,0. Interestingly this prototypes are the two, which offer the highest potential for errors. But at least, if errors occur the error message seem to be clear and helpful.

Recovering from an error was considered easy and quick in all prototypes but Single-Tag Interaction, which was rated with 1,3, whereas Multi-Tag Interaction #1 and Multi-Tag Interaction #2 both were rated with 2,3 and Multi-Tag Interaction #3 with 2,4.

Any help, which was provided either on the tag-enhanced poster or in the mobile application itself, was not that satisfying for the user. All four had very similar scores. Single-Tag Interaction was rated 1,6 and all Multi-Tag Interaction prototypes with 1,8, while Multi-Tag Interaction #3 actually was rated a bit worse than the other two, but this can not be observed due to the rounded values but figure 4.29 shows the small difference.

The information, which was needed, was not that easy to find according the users. Single-Tag Interaction was rated with 1,4, while the other three prototypes only got a slightly better rating of 1,6.

In contrast, the information that actually was found is supposed to be easy understood. All prototypes had a quite similar rating. Single-Tag Interaction, Multi-Tag Interaction #1 and Multi-Tag Interaction #2 got a rating of 2,1 and Multi-Tag Interaction #3 was rated with 2,2.

Furthermore the information for helping the user completing the task is supposedly effective. Single-Tag Interaction was rated with 1,9. Multi-Tag Interaction #1 and Multi-Tag Interaction #2 with 2,0 and Multi-Tag Interaction #3 with 2,1.

The organization of the information on the screen is especially clear using Multi-Tag Interaction #3, which was rated with 1,9. Single-Tag Interaction was rated with 1,4 and Multi-Tag Interaction #1 and Multi-Tag Interaction #2 with 1,3.

The interface was not rated as very pleasant. This could be due to the fact that the graphical design deliberately was done in a very low-fidelity style to minimize any influence on the study. Multi-Tag Interaction #3 was rated highest with 1,7. Multi-Tag Interaction #1 and Multi-Tag Interaction #2 got 1,1 and Single Tag Interaction was only rated with 0,6.

Consequently the users did not like the usage of the interface very much. Multi-Tag Interaction #3 was rated 2,0 but Multi-Tag Interaction #1 and Multi-Tag Interaction #2 only got a rating of 1,0 and Single-Tag Interaction only the very low rating of 0,4.

Asked whether the prototypes have all functions and capabilities, which are expected, the users stated to miss some functionality and rated Multi-Tag Interaction #3 with 1,5 followed by Single-Tag Interaction with 1,3 and Multi-Tag Interaction #1 and Multi-Tag Interaction #2 with only 0,9.

The last question asked for the overall satisfaction with the prototype. Once again Multi-Tag Interaction #3 got the best rating with 2,4. Multi-Tag Interaction #1 and Multi-Tag Interaction #2 were rated with 1,7 and Single-Tag Interaction with 0,9.

As already mentioned, besides the nineteen questions with Likert scales, there have been free comment fields. Some comments, which have been made are independent from the different prototypes and concern every interaction design.

Some subjects requested additional information about the meals and drinks, e.g. what topping which pizza has or also information like coke contains caffeine. Furthermore many wanted to have some information about the price of the food. Also the request for pictures for each meal has been stated more than once.

Another feature, which was requested, is the possibility to cancel an order, which has already been submitted.

One subject admitted that the start screens, with the short introduction about the usage of a certain prototype, were actually helpful but when using the application regularly and therefore being an expert user he would like to have the possibility to turn off those screens and just start ordering without any information being displayed and especially having to be confirmed.

Last but not least it was pointed out that human contact is missing especially if one has questions.

Positively noted was the fact that error messages are displayed in red and therefore are easily recognized and consequently recovering from an error is no problem.

Concerning the lists of meals and drinks with radio buttons, which have been used in both, Single-Tag Interaction and Multi-Tag Interaction #1, quite a few comments have been made. Especially high interface complexity, which forced the user to scroll, caused problems. The lists were confusing and it was not easy to get an overview of all available meals and drinks. One subject suggested to offer some kind of search or filter function or shortcut by typing the first letters of the preferred meal, which would make dealing with long lists easier. Another suggestion was to make it possible to jump from the first item to the last by scrolling up when already being at the first one and jumping from the last item to the first item by scrolling further down when already being at the last one. Another wish was that one could just hold the button to scroll and does not have to release and push the button again for each single item to scroll down or up. Some people suggested that an alphabetical order of the meals in the list would be helpful, but as one subject correctly pointed out, in a real life situation one would just browse through the offered meals and look for something that appeals to oneself instead of searching for four specified meals, which are noted on a piece of paper and are part of the user study to assure that every participant has the same general conditions. Another problem was that the highlight, which was used to navigate between the radio buttons, was always at the top of the list even if there was a meal selected way down in the list. If the user wanted to select a meal near the already selected one he still had to navigate all the way down with the highlight, which is not very handy considering that similar meals are grouped nearby and it is very possible that one already decided that one wants to have for example pizza but just another one than the one which is already selected. Generally the highlight was hard to see, which caused problems for some users.

Concerning the tag-enhanced menus the users requested more graphics e.g. photos of the meals and furthermore pointed out that the area, which is used for the menu is quite big, which makes it hard to get a full overview over the meals, because the menu is far bigger than the visual field. Furthermore users considered the menu too big for a real life restaurant.

Anyhow they liked the fact that using tag-enhanced posters, there is no scrolling through long lists.

Moreover one does not have to have the whole structure in mind when correcting something, meaning one does not have to think about the category of a certain meal one wants to change and has to explicitly navigate there, but instead one just touches the preferred meal. Anyhow some other participants pointed out that touching another tag does not feel like changing something but like adding another meal to the order.

Considering the interaction with NFC-tags also some problems arose. Firstly users would have liked a more precise information about the exact location of the NFC reader of the mobile device. Sometimes the users touched a tag and got haptic feedback, too, but anyway the tag was not read correctly. This probably occurred because they removed the phone too fast from the tag-enhanced menu. This of course caused confusion by the users. Some users also missed the haptic feedback when using the start-tag, which did not work due to implementation issues. Anyway other subjects did not like the haptic feedback in form of vibration and were rather annoyed by it. Somebody compared it to holding an electrical toothbrush.

While some liked the fact that only a NFC-tag has to be touched to open the application, others wanted to have the possibility to explicitly start the application on their mobile device without touching a tag. This is actually possible but users have not been told about it.

Concerning the start-tag, some users ran into the problem that the mobile device does not react to the start-tag if the mobile device's display is in stand-by. At least one button has to be pressed to activate the mobile device before touching NFC-tags.

More explanation was requested considering the start-tag in general. During the study each participant got an explanation about all applications and all their features, but some worried that just the start-tag labeled "Start Order" would not be enough for a first time user, who did not get any extra information from somebody else.

Another user explained that the ergonomics of holding the mobile device and touching a tag is not very pleasing. Actually touching a tag on a poster, which is clipped to a wall is more comfortable, but a menu, which is lying on the table in front of the users and results in not seeing the display while touching the tag.

Concerning just Single-Tag Interaction, the way correction worked was not liked that much due to several reasons. Firstly one has to navigate through the other categories, which one does not want to change, to get to the destined category. This was considered to be cumbersome. Secondly if browsing through the categories and selecting a meal, which is at the bottom of the list and therefore can only be seen after scrolling down there, one did not see which meal is selected or if there is any selection made at all. This was confusing for the users because they were afraid that their selection was discarded while navigating back and forth. Another user pointed out that the short introduction text at the beginning of the mobile application should not only tell the user about the "next"-button but also inform that one can always return and change one's order by using the "back"-button. Some complained that one has to click quite a lot, which also is quite straining for the thumb, which carries out the interaction. One person also stated, that he would like to have more feedback after each selection of a meal, for example something similar as the haptic feedback, while touching a tag to select a meal. Furthermore the usage of NFC was not seen as a big advantage since it was only used for starting the application and besides that it did not add any extra features to the application. One person mentioned that in general he did not consider the application suitable for food ordering. But of course also some positive statements have been made. Single-Tag Interaction is considered to be a linear classical approach, which guides the user through the application. The user is already accustomed to similar applications and therefore ordering seems to be quick and easy. One subject stated that he has the feeling that selection via the lists is faster because he does not have to search for the desired option on a huge poster. But according to the measured execution times, this assumption is not correct. One person stated that it is nearly impossible do make an error using this design and it is easy to learn. Furthermore some subjects especially liked that there is no mixture of interaction with the mobile device and the tag-enhanced poster and therefore nearly no attention shifts are needed and one does not necessarily need the NFC-tag, since of course the application could be started with the help of the menu of the mobile device and therefore the user does not need to learn the handling of this new technology. Changing previously selected items with the "back"- and "next"-buttons had one advantage for the user. They really had the feeling they were changing the old selection, whereas when touching another NFC-tag of a previously selected category, some had the feeling to add something to the order instead of changing it. One person stated that he could imagine this kind of prototype for home-ordering since one probably does not want to store huge tag-enhanced menu cards at home.

Using Multi-Tag Interaction #1 many subjects did not enjoy the necessity of the high number of attention shifts between mobile device and tag-enhanced menu. Besides the already mentioned problems concerning the long lists, using Multi-Tag Interaction #1, the radio buttons caused some problems because by scrolling through the lists only the highlight is moved but not the actual selection. The final selection has to be done by a key press, in this case the left soft key with the label "Ok". In Single-Tag Interaction this confirmation was given by pressing "Next", which had to be done anyway to proceed with the ordering process. Due to the fact, that the next category was selected by touching another NFC-tag the explicit confirmation by pressing "Ok" was often forgotten, which resulted in frustration because the user believed he had already selected a certain meal for a category but it was not listed in the summary. Moreover it was not intuitive for some how to make corrections to the already selected meals. And one would prefer to submit the order by a key press on the mobile device instead of a dedicated submit-tag. All in all many stated that they had to press way too many keys to complete the order and that everything took way too long. Anyhow many users also stated Multi-Tag Interaction #1 to be easy to use, quick, self-explaining and effective and it is similar to other mobile applications, which one already knows and therefore only a short time to get used to it is needed. Although some were irritated by the way one can change previous selected meals others stated that they would prefer that compared to Single-Tag Interaction and its very linear structure. Furthermore it was noticed positively that the tags on the menu were sorted in the order one usually needs them starting with the start-tag, followed by the different categories and at last the submit-tag. This gives the user some kind of structure similar to a wizard but not as inflexible as an actual wizard because it is possible to break out of the order and select the categories in which ever way one likes.

Starting Multi-Tag Interaction #2 with the help of the menu was noted to be less comfortable than a dedicated start-tag. Subjects, which beforehand tested one of the other applications, were actually surprised about this way and were searching for a start-tag before realizing that they need to start the application with help of the mobile device's menu. Furthermore the wizard-like structure, which forced the user to select the meals in the given order, was not liked at all and described as uncomfortable and did not correspond to a real life situation where one often orders the drink first. Moreover the way correction was handled, was not very enjoyable for the users.

Besides, as one subject correctly pointed out, a first time user does not know that, at least in the end, it is possible to change already selected options and might abort the order and start from the beginning if he changes his wishes or accidently touches a wrong NFC-tag. All in all users wished for more help and guidance using this prototype. Especially handling the NFC-tags and NFC reader, which of course are part of a completely new interaction style and therefore seem a bit complicated and unconventional. One subject explicitly pointed out that he would feel quite awkward using this technology in a real restaurant. Furthermore one user complained about having to press too many buttons, which probably hints at all the times where the user has to press "Next" after selecting one course, but this in fact is optional. As long as the user stays in the correct order he can go on choosing a meal without pressing "Next". Anyhow they enjoyed the quick overview of the menu, which was not given using Single-Tag Interaction or Multi-Tag Interaction #1. They considered Multi-Tag Interaction #2 to be self-explaining, intuitive, easy and quick to use. Furthermore the messages provided on the display of the mobile device helped the user to get through the process of ordering and the soft key with the label "Correction" is considered to be a good example for the self-explanatory nature of the application. Last but not least one subject stated that the placement of the submit button on the mobile device in contrast to a dedicated submit-tag gives him the feeling of being more in control.

Using Multi-Tag Interaction #3 the subjects enjoyed the quick and easy selection and considered the design to be very intuitive and fast. Somebody actually labeled it "foolproof". Correction was stated to be easy and while using Single-Tag Interaction or Multi-Tag Interaction #2 people complained about the fact that they cannot order a drink first, it was positively noted that this is possible with Multi-Tag Interaction #3. Some mentioned that they were happy that they did not have to switch between touching tags and pressing buttons on the mobile device. Anyway some pointed out that they would prefer to submit the order with a button on the mobile device because they feel more in control doing it this way. Moreover, as one subject pointed out that the fact one does not need to press any buttons could lead to the problem that the user does not look at the display of the mobile device and does not properly check his order before actually submitting it. Concerning the submit-tag on the poster many stated that they would have assumed it to be at the button of the poster and not at the top next to the start-tag. Furthermore one sometimes could monitor users starting ordering without touching the start-tag and wondering why it did not work. Another problem in this case is the fact that, without touching the start-tag no application is started and therefore no helpful error message can be given to the user besides the standard message, which is provided by the manufacturer of the mobile device. Anyway one person explicitly stated that he would like to start ordering without having to start the application at all. He wished that by touching any tag the mobile device would recognize to which application this tag belongs and therefore start it.

Closing Questionnaire

In the closing questionnaire the subjects have been asked to compare all four prototypes, which have been presented to them.

As first question they were asked, which prototype they preferred. All sixteen participants named Multi-Tag Interaction #3 as their favored interaction design. In the free comment field for further explanations about their decision, they stated that they considered it to be the most intuitive and easiest prototype. Furthermore they liked that they did not have to switch between buttons on the mobile device and NFC-tags on the poster but only could use NFC-tags for the whole ordering process. It was considered to be more comfortable to read the meals and drinks on the tag-enhanced poster instead of the small display because it is more clearly arranged and the font size is bigger. Also starting the application via the dedicated start-tag was stated as reason to prefer Multi-Tag Interaction #3 as well as the easy correction method and the liberty in the order of the selection process. Multi-Tag Interaction #3 gave the subjects the feeling of being in control instead of being controlled and limited by the application. All in all the application does not really feel like a mobile application but more like a real object, which is used for interaction. Furthermore one could integrate the NFC-tags in an already existing menu.

Being asked about the prototype, which suits the task least, the subjects are not as united as in the previous question. Seven disliked Single-Tag Interaction the most, six subjects named Multi-Tag Interaction #1 and three users named Multi-Tag Interaction #2. The ones who named Single-Tag Interaction stated that the usage of NFC-tags did not add any benefit to the application and they detested the long lists and the scrolling through them as well as the given order of the selection process. Multi-Tag Interaction #1 was mainly not like because of the many attention shifts between the mobile device and the tag-enhanced poster. Furthermore like with Single-Tag Interaction the long lists were not appealing to the users. Using Multi-Tag Interaction #2 they complained about the strict order of the selection process as well as the rather uncomfortable way of correcting and changing one's previous selections.

Being asked, which interaction - just using the mobile interface, just using the tag-enhanced poster or using both equally - they would prefer, most subjects opted for using tag-enhanced posters. Reasons for their choice were that they consider it to be fast and intuitive, it led to far less attention shifts, it is more clearly arranged especially with long lists and less key presses were needed. Furthermore it was stated that it might be an easier interaction style for people, which are not that accustomed to dealing with mobile applications because dealing with buttons on the mobile device is minimized. One subject states that using NFC-tags somehow feels "magical". Besides the thirteen people, who chose tag-enhanced posters, none chose mobile interface only, but three would like the combination of both. Reasons for that were that users feel more in control when pressing a key on there mobile device instead of touching a tag in crucial situations like submitting an order. Furthermore they liked the feedback that was presented on the mobile device.

Following, the subjects have been asked about parts of the whole interaction process and if they prefer to conduct those steps either on the mobile device itself, on the tag-enhanced posters or with both equally. Starting the application is preferred to be done via a dedicated start-tag by eleven participants, four participants like both ways equally and one person prefers starting with the help of the mobile device's menu. The navigation, more precisely switching between the different categories, is preferred to do with the help of the posters by twelve subjects whereas four do not mind if they use tag-enhanced posters or the mobile device. Choosing between the different meals and drinks is preferred to be done with the help of NFC-tags on posters by fourteen people, while one person prefers to do it on the mobile device and one person does not care if it is done on a poster or on the mobile device. Carrying out execution actions, like for example submit, only three people prefer the poster, whereas six subjects opted for the mobile device, which is not surprising since this was already stated on several occasions by the participants. Seven participants are open for both options, a key press on the mobile device or touching an NFC-tag. The summary, which was presented to the user in the end, is preferred to be shown on the mobile device by twelve participants. Only three people would prefer it on a poster respectively in this case some kind of dynamic display, which offers the possibility to give feedback of this kind. One person does not care where the feedback is presented and likes both options. Ten participants prefer to correct errors with the help of the tag-enhanced poster, four would prefer correction on the mobile device and two like both options. Hints about the usage of the application should be given on the mobile device according to six participants whereas three would prefer them to be on the poster and seven like both options.

Guidance and structure to carry out the task should either be offered by the poster (eight subjects) or there should not be any forced order to carry out the ordering process (seven subjects). Only one subject opted for the mobile device to guide the user through the application.

Being asked about problems, which arose while using the prototypes, many subjects stated the wizard-like structure of Multi-Tag Interaction #2, which forced an order of selection on them as well as the correction mode, which only made correction at the end possible. Generally correcting one's previous selection with the help of NFC-tags irritated some users because they had the feeling that they added another meal to their order instead of replacing the previous selected one. Furthermore the confirmation of the selection while using Multi-Tag Interaction #1, which has to be done before touching another NFC-tag, was often forgotten and therefore caused problems.

Suggestions for improvements have been a more graphical design for the tag-enhanced posters like photos of the meals, probably instead or just with a small NFC-symbol as well as additional information like the price of each meal. Furthermore extra features like for example an option for extra cheese would be possible. The missing haptic feedback, when using a start-tag, was requested as well as an extra button on the mobile device to submit the order instead of the submit-tag. Considering the application on the mobile device subjects suggested a way to sort the rather long lists either alphabetically or by theme. Furthermore they asked for a bigger font size.

Generally they stated that both ways, lists and posters do work, but the switching between posters and mobile application was kind of stressful. Single-Tag Interaction, which mostly only relied on the mobile interface on the device could be imagined for home-ordering. All in all Multi-Tag Interaction #3 was supposed to be the easiest prototype.

5 2nd User Study: Actions and Objects

The second user study focuses on the pattern "Combination of Information", which is introduced in 3.3. Once again a prototype offering Single-Tag Interaction as well as several slightly differing prototypes using Multi-Tag Interaction are presented to the participants.

5.1 Basic Use Case

The basic use case consists of a subject standing in front of a tag-enhanced map of the city center of Munich. These maps could be imagined to be standing all around Munich and offer information about several sights as well as the option to mail the information to a friend. Furthermore the user can plan a route to get to several sights. During the study it is evaluated, which interaction style and which combination of tags and direct input on the mobile device is preferred.

The basic workflow can be seen in figure 5.2. Having started the application, the welcome screen, which offers a short introduction, is presented. In the next step the user has to select a sight either by selecting one out of a list presented on the mobile device or by touching a sight-tag. Afterwards there are three different options. If the user selects "Information", he gets information to the previous selected sight on his device's screen. Alternatively he selects "Route" and is asked to add more sights. Having done that he will be displayed the route. The third option is "eMail". Choosing this, the user has to select a contact to send the email to and afterwards he will get a confirmation about the successful sending of the e-mail.

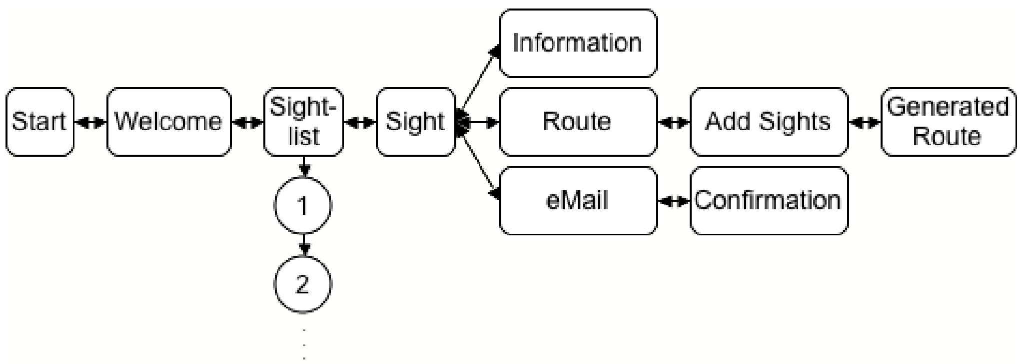

Figure 5.1: The basic workflow of the tasks belonging to the second user study.

Five different prototypes are presented to the user. Each prototype consists of a mobile application and a tag-enhanced poster. Every poster contains a start-tag to launch the application on the mobile device. Depending on the prototype there are also so-called sight-tags for the seven offered sights: "Stachus", "Sendlinger Tor", "Frauenkirche", "Viktualienmarkt", "Hofgarten", "Isartor" and "Deutsches Museum". Furthermore some prototypes contain so-called action-tags representing the three actions: "Information", "Route" and "Send eMail". The map of Munich is taken from [23].

Carrying out the different tasks, the user has to combine objects, which in this case are represented by sights, and actions. Depending on the prototype, the actions and sights are either selected using the mobile interface or placed on the poster for selection. All possible distributions for "Combination of Information" were covered by the different prototypes as depicted in figure 5.2

Action \ Object	Handy	Poster
Handy	STI	MTI #1
Poster	MTI #2	MTI #3 MTI #4

Figure 5.2: Covering all possible combinations of "Objects" and "Actions" distributed on the mobile interface and the physical interface.

5.1.1 Single-Tag Interaction

Figure 5.3 shows the tag-enhanced map for Single-Tag Interaction. The user is presented the city center of Munich and seven sights with corresponding photos. In this case those only serve as visual aid but there is no functionality integrated into the map. The only tag on this poster is the start-tag, which launches the application. All posters in this user study are printed as DIN A1.

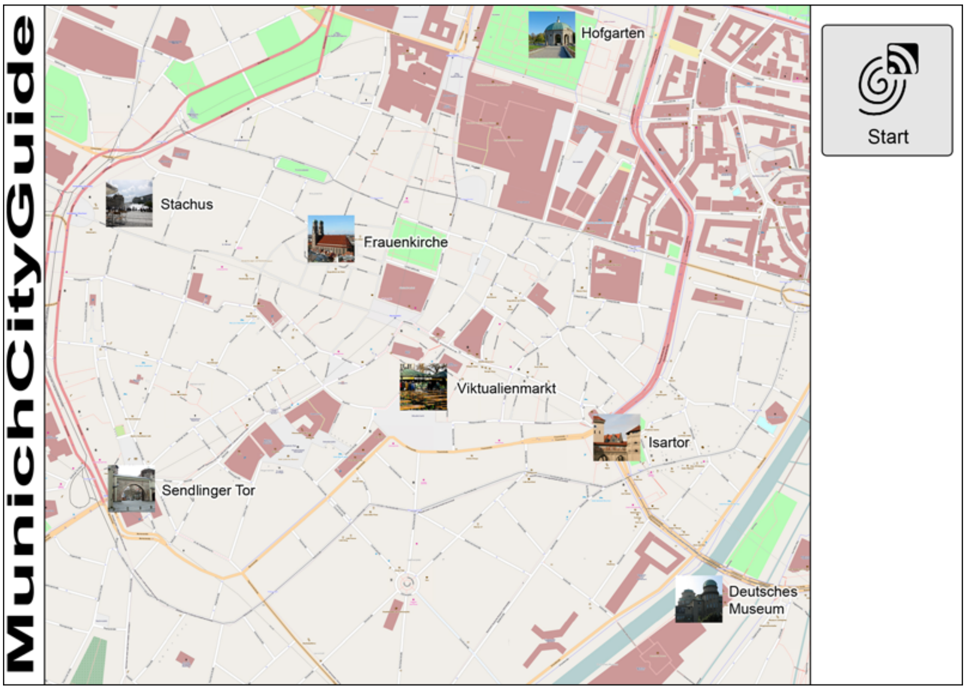

Figure 5.3: The tag-enhanced map for Single-Tag Interaction consisting only of one tag - the start-tag.

Figure 5.4 depicts the first part of the mobile application for Single-Tag Interaction. Having started the application the user is presented a welcome screen with a short instruction (a). After pressing "Ok" the second screen (b) shows a list of all seven available sights. The user is supposed to select one of them by using the arrow keys and after pressing "Ok" he is presented the screen for the chosen sight (c). The screen (c) offers a menu labeled "Options", which is available through the left soft key. Screen (d) shows the contents of the menu. There the user can select one of the three actions, which can be applied to each sight.

Figure 5.4: Parts of the mobile application for Single-Tag Interaction.

Figure 5.5 shows as first screen some information about a sight (a), which is displayed after having selected the menu item "Information". Pressing the back button the user gets back to the sight screen and can choose another option from the menu for the selected sight. Screen (b) and (c) show the "Send eMail" feature of the mobile application, which offers to send the information to a friend. At first the receiver is chosen and by pressing "Send" the email is sent to the selected person.

Figure 5.5: The screen for the action "Information" as well as the screens for the action "Send eMail" for Single-Tag Interaction.

In figure 5.6 one can see the screens belonging to the action "Route". Having selected this action the user gets presented a screen, which states the currently selected sight and furthermore requests to select a second sight (a). Having pressed "Ok" the user will see the same list of sights (b) as depicted in figure 5.4 but selecting a sight this time will add it to the route and therefore it will be listed on screen (c). Being on this screen the user either decides to add another sight and gets back to screen (b) or he proceeds to generate the route, which is shown in screen (d). In the prototype there is no actual routing functionality implemented and therefore independent of the previously selected sights the user will always be presented the same dummy route.

Figure 5.6: Screens for the action "Route" for Single-Tag Interaction.

5.1.2 Multi-Tag Interaction #1

Besides the start-tag, Multi-Tag Interaction #1 offers a tag for each sight as depicted in figure 5.7. Instead of having to choose the sight one is interested in from a list on the mobile device, the user can simply touch the sight's corresponding tag on the map.

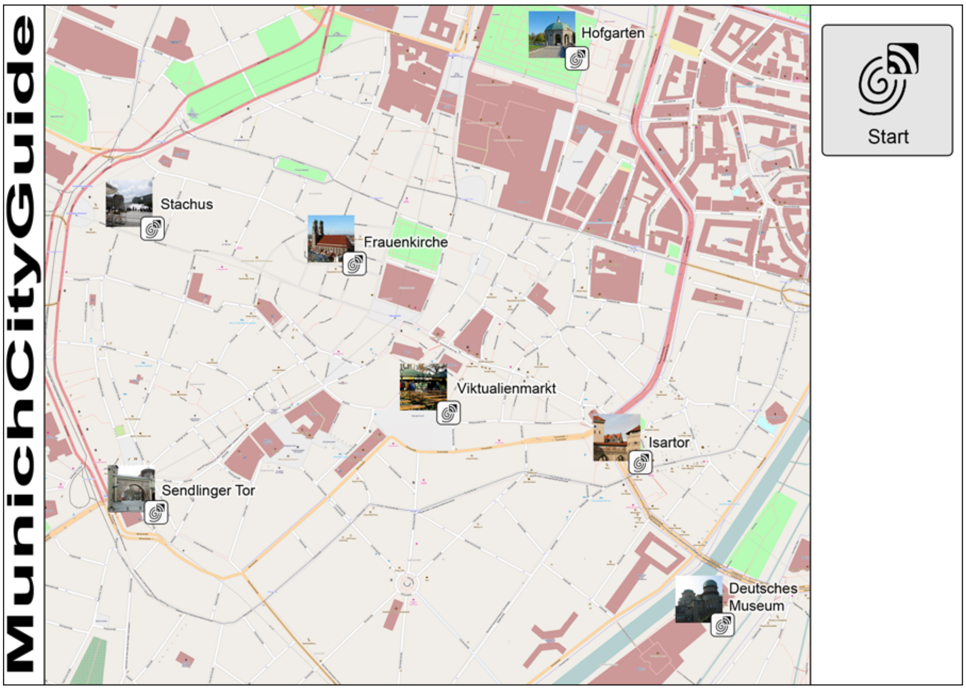

Figure 5.7: The tag-enhanced map for Multi-Tag Interaction #1 offering a start-tag and at tag for each sight.

Consequently as shown in figure 5.8, in comparison to Single-Tag Interaction, the screen with the list of sights is missing. Except that the sequence of screens is completely the same as in Single-Tag Interaction. At first the user is presented a welcome screen (a) and some basic instruction where he is asked to touch a sight. Having touched a sight, the corresponding screen (b) is shown and the user can select an action with the help of the option menu (c).

The actions "Information" and "Send eMail" look exactly the same in the mobile application of Multi-Tag Interaction #1 as in the mobile application for Single-Tag Interaction as depicted in

Figure 5.8: Parts of the mobile application for Multi-Tag Interaction #1.

figure 5.5.

Concerning the action "Route" there is once again a slight difference. Like at the beginning of the application, the list of sights is missing, because a second sight is added just by touching a sight on the map. This leads to the three screens as depicted in figure 5.9.

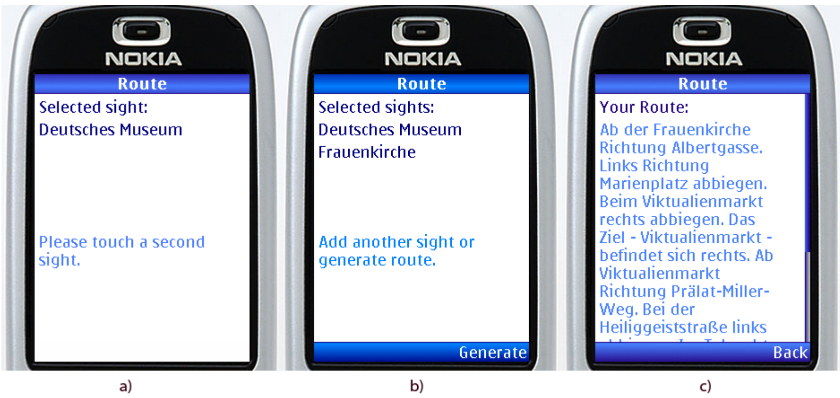

Figure 5.9: Screens for the action "Route" for Multi-Tag Interaction #1.

5.1.3 Multi-Tag Interaction #2

The poster of Multi-Tag Interaction #2, which is shown in figure 5.10, consists of the same map as all posters but in contrast to the map of Multi-Tag Interaction #1 there are no sight-tags but three action-tags below the start-tag for "Information", "Route" and "Send eMail".

Using the mobile application, after having touched the start-tag, the user once again gets presented the startscreen (a) as depicted in figure 5.11. Pressing "Ok" leads him to the list of sights (b) from which he can choose the sight he wants to use. Having chosen a sight the user sees the screen for the sight (c) but in contrast to the sight-screens of the previously presented prototypes, this time there is no options menu. Instead of using the menu the user has to touch one of the action-tags.

Choosing the action "Information", "Route" or "Send eMail" will lead to the exact same screens as in Single-Tag Interaction, which can be seen in figure 5.5 and figure 5.6.

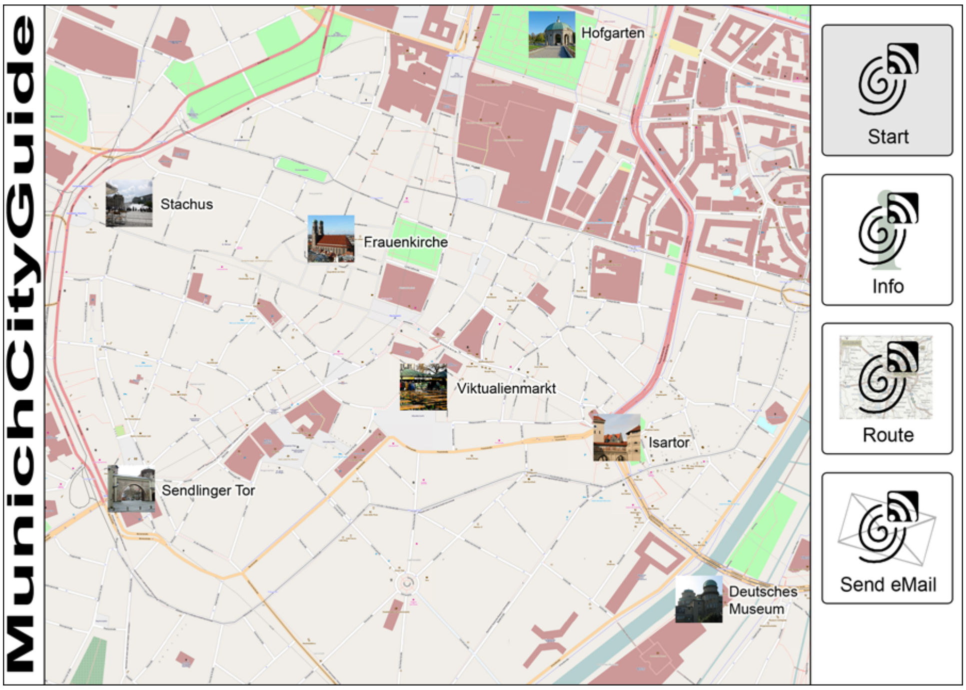

Figure 5.10: The tag-enhanced map for Multi-Tag Interaction #2 offering a start-tag and tags for each action.

Figure 5.11: The first parts of the mobile application for Multi-Tag Interaction #2.

5.1.4 Multi-Tag Interaction #3

Concerning the tag-enhanced map, Multi-Tag Interaction #3 is a combination of Multi-Tag Interaction #1 and Multi-Tag Interaction #2. The poster, as depicted in figure 5.12, contains sight-tags as well as action-tags.

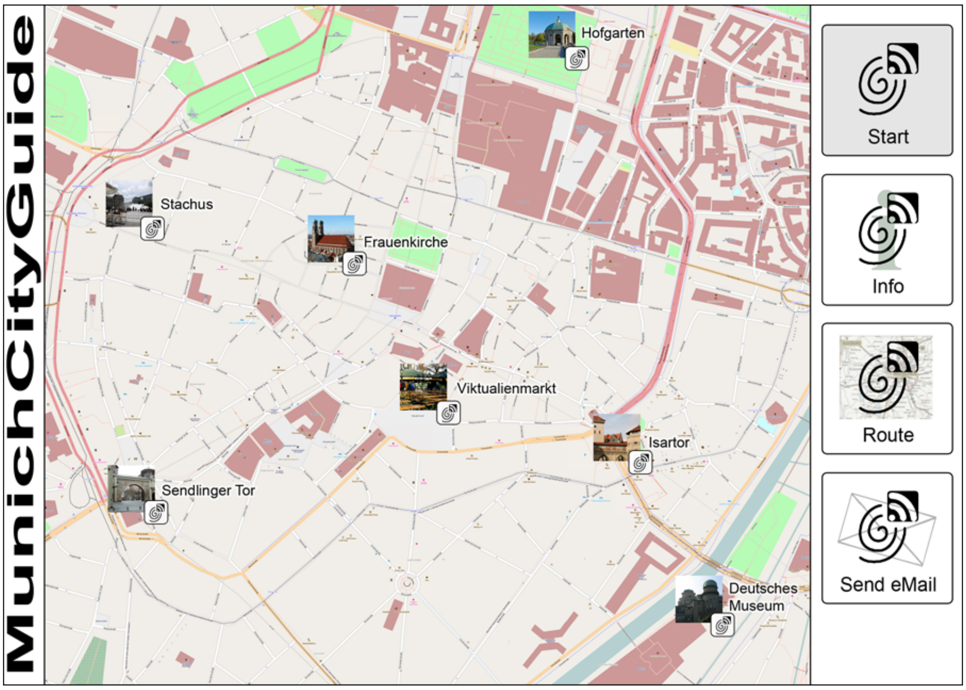

Figure 5.12: The tag-enhanced map for Multi-Tag Interaction #3 offering a start-tag, tags for each sight and tags for each action.

This layout leads to the possibility to either start with choosing a sight or choosing an action. As figure 5.13 shows, after launching the application and viewing the startscreen (a) the user either sees the selected sight or the selected action on his mobile device (b). Having chosen a sight first the second tag of course has to be an action-tag or vice versa having chosen an action the second tag has to be a sight-tag.

Having touched two tags - one sight-tag and one action-tag - the user will be directed to the corresponding screen, either the "Information" screen, the "Send eMail" screens or the "Route" screens. Those screens look exactly as in Multi-Tag Interaction #1, respectively the "Information" screen and the "Send eMail" screens are also the same as in Single-Tag Interaction. All screens to the three actions can be seen either in figure 5.5 or 5.9.

5.1.5 Multi-Tag Interaction #4

The poster of Multi-Tag Interaction #4, as shown in figure 5.14, offers three tags - "Information", "Route" and "Send eMail" for each sight.

Having touched the start-tag the application is opened and the user will see the startscreen as depicted in figure 5.15. Afterwards he can touch any of the tags on the map and will be directed to the desired content. The screens for "Information", "Route" and "Send eMail" look exactly the same as in Multi-Tag Interaction #1, shown in figure 5.5 and 5.9 with one small difference, the back button on all screens is missing. This is because there is no reason to return to a previous screen because switching between different sights or actions is done just by touching one single other tag.

Figure 5.13: The first parts of the mobile application for Multi-Tag Interaction #3.

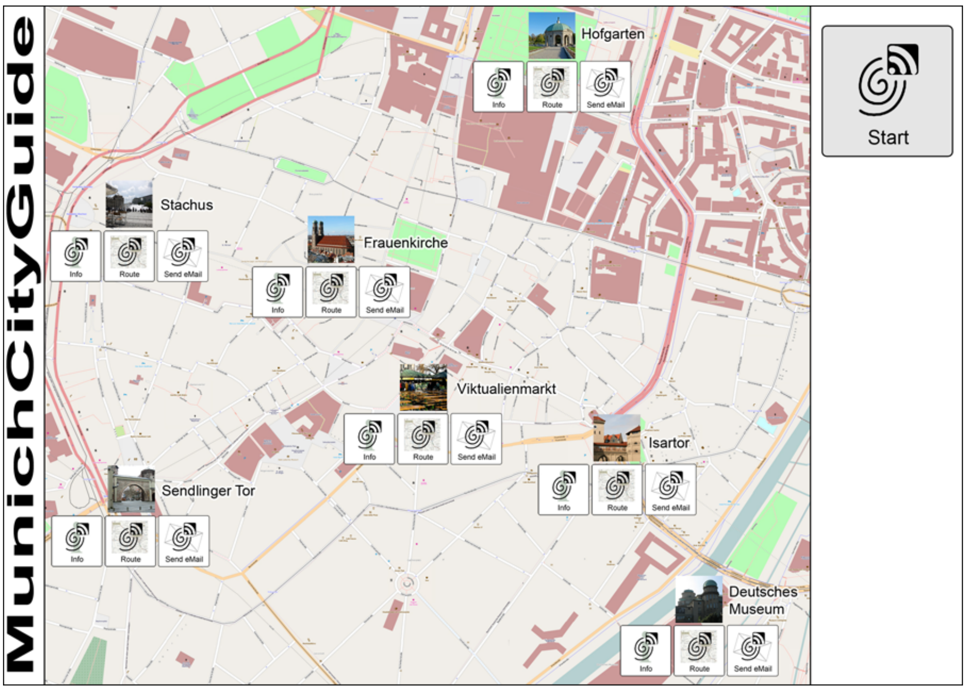

Figure 5.14: The tag-enhanced map for Multi-Tag Interaction #4 offering a start-tag and for each sight three action tags.

Figure 5.15: The first parts of the mobile application for Multi-Tag Interaction #4.

5.2 Implementation

The implementation of the prototype of the second user study is analog to the implementation of the prototype of the first user study described in 4.2.

Once again the prototype consists of two parts: the mobile application and the tag-enhanced poster. Both will be described briefly in the following.

5.2.1 The Mobile Application

As well as the first prototype, the application was designed using Jave ME, the Nokia 6131 NFC SDK and J4ME for the graphical user interface. Anyway the second prototype makes use of more interface widgets than the first prototype. Besides the adapted checkboxes, which lets them behave like radio buttons (as described in 4.2.1), the prototype includes images and a submenu. In contrast to the checkboxes respectively radio buttons there have not been made any adaptions to the functionality and look and feel of the images and the submenu but the standard implementation provided by J4ME has been used.

The integration of the NFC technology has been carried out using the same code as in the first user study's prototype.

5.2.2 The NFC-Enhanced Poster

The posters have been enhanced with sticky Mifare Standard 1k NFC tags. Usually behind each NFC-symbol one tag is placed. Additionally, to realise the big areas on the right on the poster containing start tags or action tags (e.g. shown in 5.12), four tags have been placed behind each of those boxes with the same content. Consequently the user has a bigger area to aim.

Of course, analog to 4.2.2, there are two types of tags. The start-tags used with the PushRegistry to start an application and "normal" tags, which only contain text and are used for the interaction. Although the tags on the poster are divided into action-tags and sight-tags, from the implementation's side, they are all the same.

5.3 User Study Design

Analog to the first user study the evaluation aims to find out, which distribution of objects and actions is the most enjoyable and suitable concerning execution time, errors and attention shifts.

5.3.1 Experimental Design

In the following the basic outline of the user study design will be presented.

Hypotheses

The following hypotheses have been established beforehand and are supposed to be confirmed or confuted.

- H1: Single-Tag Interaction is slower compared to all designs for multi-tag interaction.
- H2: Performance regarding task completion time and number of errors improves from single-tag interaction to multi-tag interaction in the following order: Single-Tag Interaction, Multi-Tag Interaction #1, Multi-Tag Interaction #2, Multi-Tag Interaction #3 and Multi-Tag Interaction #4. But the number of attention shifts increases.
- H3: Combination of tags as in Multi-Tag Interaction #3 is liked best followed by combined tags used in Multi-Tag Interaction #4.

Independent Variables

All in all two independent variables are tested: design and task.

Design has five levels representing the five different prototypes Single-Tag Interaction, Multi-Tag Interaction #1, Multi-Tag Interaction #2, Multi-Tag Interaction #3 and Multi-Tag Interaction #4, which have been described in 5.1.

The independent variable task has three levels, "Information", "Route" and "Send eMail". "Information" combines one object with one action. "Route" combines several objects with one action and "Send eMail" combines an option, an action and some additional information, which is already stored on the mobile device.

The following three task descriptions are given to the subjects to carry out the three levels of the variable task with each prototype.

1. Information:

   You are standing in front of the MunichCityGuide poster in Munich and you want to acquire information about "Sendlinger Tor".

2. Route:

   You are standing in front of the MunichCityGuide poster in Munich and you want to get a route, which leads you to the following sights:

   - *Frauenkirche*
   - *Viktualienmarkt*
   - *Isartor*
   - *Deutsches Museum*

3. Send eMail:

   You are standing in front of the MunichCityGuide poster in Munich and you want to send an e-mail with information about "Hofgarten" to Eva Meier.

Dependent Variables

Along the lines of the first user study the independent variables, which are measured, are: execution time, number and kind of errors and number of attention shifts.

Similar to the first user study a timer is implemented in every prototype and measures the time in milliseconds from touching the start-tag until finishing the task and stores it in the RecordStore of the midlet, which can be read by the investigator.

Furthermore the execution of the user study is taped on video after having asked the participants for their consent. This video material is used to count the macro attention shifts between the mobile interface and the tag-enhanced poster made by each user while carrying out the tasks.

Errors are already noted during the actual execution but with the help of the video analysis those notes are refined to be the most accurate possible.

Latin Square

The user study was conducting using a within subjects or repeated measures experimental design [10] similar to the first user study. Consequently the same advantages as well as disadvantages of repeated measures design, as described in 4.3.1, do apply here, too.

To avoid learning effects or any other side effects, which can be caused by asking subjects to carry out different but similar tasks, a latin square design was applied. Designing the latin square, one has to keep in mind that the whole study is based on a multivariate design consisting of two independent variables, design and task.

Design has five levels, meaning the five different prototypes, whereas task has three levels, the actions "Information", "Route" and "Send eMail". Consequently two latin square designs have to be combined. Figure 5.16 shows the latin square for the variable design and figure 5.17 shows the latin square for the variable task.

Order of Design				
Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2	Multi-Tag Interaction #3	Multi-Tag Interaction #4
Multi-Tag Interaction #1	Multi-Tag Interaction #3	Single-Tag Interaction	Multi-Tag Interaction #4	Multi-Tag Interaction #2
Multi-Tag Interaction #2	Multi-Tag Interaction #4	Multi-Tag Interaction #3	Multi-Tag Interaction #1	Single-Tag Interaction
Multi-Tag Interaction #3	Single-Tag Interaction	Multi-Tag Interaction #4	Multi-Tag Interaction #2	Multi-Tag Interaction #1
Multi-Tag Interaction #4	Multi-Tag Interaction #2	Multi-Tag Interaction #1	Single-Tag Interaction	Multi-Tag Interaction #3

Figure 5.16: Latin square for the independent variable design.

Combining these two, one assures that no participant carries out the tasks in the exact same order as another participant. Figure 5.18 shows the actual list of tasks for the first participant. At first he carries out all tasks using Single-Tag Interaction. The order of the tasks is "Information", "Route" and as third "Send eMail". Afterwards all tasks get carried out with the help of Multi-Tag Interaction #1 and so on.

Order of Task		
Information	Route	Send Email
Send Email	Information	Route
Route	Send Email	Information

Figure 5.17: Latin square for the independent variable task.

	#1	#2	#3	#4	#5
Design	Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2	Multi-Tag Interaction #3	Multi-Tag Interaction #4
Task	Information	Send eMail	Route	Information	Send eMail
Task	Route	Information	Send eMail	Route	Information
Task	Send eMail	Route	Information	Send eMail	Route

Figure 5.18: Latin square for the first participant.

5.3.2 Conducting the User Study

The actual study is carried out with fifteen participants. Of course this number is derived from the latin square design. Fifteen is divisible by five as well as three and therefore the latin squares can be applied quite easily.

At first each participant is given some basic instructions about the user study and everyone is asked for their permission to record the user study on video. Afterwards the user is supposed to fill out an introducing questionnaire (see appendix), which asks for some demographic data and information on their technical background and experience.

In the following the participant will carry out all tasks with all prototypes according to the order given by the latin square. Generally the procedure is like that. At first the user gets a short verbal introduction about the overall usage of NFC and about the basic use case. He is asked to perform a trial execution and gets to know the features of the prototype and how to use them. Once he feels familiar with the prototype the actual tasks are presented to him one after another.

Having finished all three tasks with one prototype the user is asked to fill out the abbreviated IBM "Computer System Usability Questionnaire" (see appendix). The abridgment was done due to experiences made during the first user study. Some questions were not suitable for the tasks and irritated the users when being asked. Those have been removed to offer a questionnaire, which covers all important aspects but does not confuse the user. Anyway, like the original "Computer System Usability Questionnaire" [24], the questionnaire consists of different questions, which are answered using a Likert scale with seven levels and additionally an option for "not applicable". Furthermore there are free comment fields for positive as well as negative feedback and a free field for any other thoughts or suggestions on the prototype.

After having used all five prototypes the user was asked to fill out the closing questionnaire (see appendix), where he was asked to compare the five presented prototypes as well as to give his opinion on the question, which functionalities are supposed to be carried out with the help of physical mobile interaction or on the mobile device itself.

Figure 5.19 gives some impressions from the conduction of the second user study.

Figure 5.19: Conducting the user study. Subject starting the application with the help of the start-tag, using the mobile application to choose an action, touching a tag to acquire information about "Sendlinger Tor" and filling out the modified IBM questionnaire.

5.4 Evaluation of the User Study

All collected data concerning the dependent variables, attention shifts, errors and execution time, is evaluates using SPSS [9]. Kolmogorov-Smirnov is used to analyze normal distribution and a repeated measure Anova is applied. Furthermore all qualitative data is summarized.

5.4.1 Demographics and Technical Background

At the beginning of the user study each participant was asked to fill out a demographic questionnaire (see appendix). From the fifteen people, who took part, eight were male and seven female. Their average age was 23 years. All participants are students: twelve study media informatics, one computational linguistics, one geography and one mechanical engineering. As one can see, nearly all have a technical background.

All fifteen persons own a mobile phone, on average for 6,9 years. On a Likert scale from one to five, they rated their experience with mobile devices with 3,8.

With the exact same value of 3,8 they rated their overal technical knowledge. Eleven participants have heard of either RFID or NFC but only three people already took part in a user study concerning the NFC technology.

5.4.2 Attention Shifts

In the following, when talking about attention shifts, only macro attention shifts between the mobile interface and the physical interface are considered. These attention shifts are counted using video analysis.

The Kolmogorov-Smirnov test can only be applied to test cases where the number of attention shifts has not been totally equal throughout all participants. This sometimes happens, if the design forces a certain order of execution on the user, like Single-Tag Interaction, where the user has to touch the tag and afterwards switches to the mobile interface and everything is carried out using the mobile device. Consequently every user executed exactly one single attention shift. The task "Information" carried out with Multi-Tag Interaction #1 and Multi-Tag Interaction #4 also cause a complete equal number of attention shifts. But all other design and task combinations could be evaluated using Kolmogorov-Smirnov. The Tests of Normality were highly significant for all of them, hence the distribution is not normal.

Having a look at Mauchly's Test of Sphericity one can see that all two independent variables and their combination is highly significant and therefore the condition of sphericity is not met and some conditions are more related than others.

Figure 5.20 shows the means and standard deviations for each prototype and each task. As already mentioned, using Single-Tag Interaction, the users all performed exactly one attention shift (for all task: m=1,00; sd=0,00) because there was only one single tag to be touched and all further input has been done on the mobile device itself.

Considering Multi-Tag Interaction #1 the number of attention shifts for the task "Information" is also constant (m=3,00; sd=0,00). The user needs to start the application, switches back to his mobile device, uses the poster again to select a sight and then moves his attention back to the mobile device to select the action "Information". Carrying out "Route" the user has to select more than one sight directly in series. Some participants did check the mobile device's display in between to check whether the NFC reading was successful, others trusted the haptic feedback that was given after a tag was touched and did not shift their attention. Consequently in this case the number of attention shifts was not constant (m=6,71; sd=1,72). Using the function "Send eMail", one would expect a constant number because similar to "Information" only one tag, beside the start-tag, has to be selected. But one participant needed more attention shifts due to a reading error of the NFC-tag (m=3,13; sd=0,52).

Getting information with Multi-Tag Interaction #2 also seems to cause a constant number of attention shifts but one user was searching for sight-tags and therefore switched one time more between the mobile device and the physical interface (m=2,13; sd=0,51). Also using "Route" a not constant number was caused due to errors. Two participants did not know when to touch the route-tag and touched it multiple times during the execution of the task (m=4,13, sd=0,35). Sending an e-mail, two users not only touched the "Send eMail" tag but also the "Information"-tag

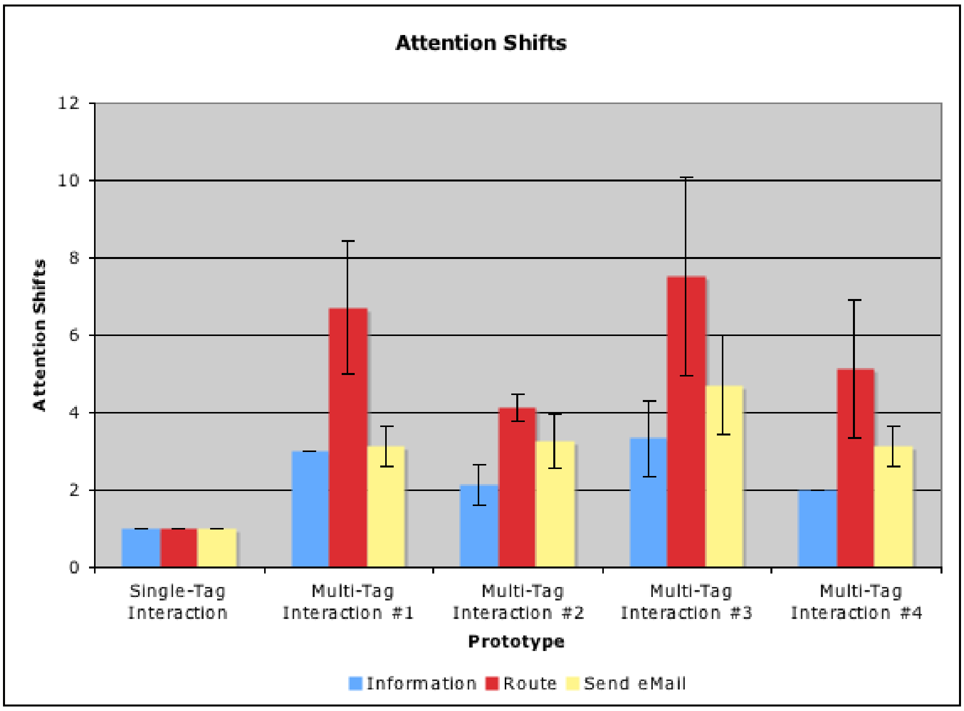

Figure 5.20: The mean and standard deviation of the attention shifts for all five prototypes and all scenarios.

wanting to add information to the e-mail, although this was not necessary. Therefore the number of attention shifts is once again not constant (m=3,27, sd=0,70)

In Multi-Tag Interaction #3, the user has to combine sight-tags with action-tags and therefore more than one tag has to be touched in series and depending on their trust in the haptic feedback the attention shifts differ a lot, which led to the following results: For "Information" a mean of 3,33 and a standard deviation of 0,98, for "Route" a mean of 7,53 and a standard deviation of 2,56 and for "Send eMail" a mean of 4,71 and a standard deviation of 1,28.

Using Multi-Tag Interaction #4 only generating a route led to a series of tags, which had to be touched. Therefore "Information" had a constant number of attention shifts (m=2,00; sd=0,00) while "Route" has a mean of 5,13 and a standard deviation of 1,77. "Send eMail" could have had a constant number of attention shift but once again users tried to add information to the e-mail by additionally touching the information tag and therefore the number of attention shifts is not constant (m=3,13; sd=0,52).

To sum up one can say that only if more than one tag has to be selected in series it is natural that the number of attention shifts differs. In any other case a differing number of attention shifts has been caused by errors of the user.

The values of the Within-Subjects Effects for all variables are significant. Consequently the rating was affected by the independent variables.

Finally, having a look at the Pairwise Comparison output with Bonferroni Correction of the Anova, design is mostly significant but not for all levels. Changing between Multi-Tag Interaction #1 and Multi-Tag Interaction #3 and changing between Multi-Tag Interaction #2 and Multi-Tag Interaction #4 is not significant and therefore does not have an influence on the number of attention shifts. This can also be observed in figure 5.20.

5.4.3 Errors

Due to the fact that all users were supposed to check out each prototype and make themselves familiar with its usage only very few errors have been made during the execution of the given tasks, which can also be seen in figure 5.21.

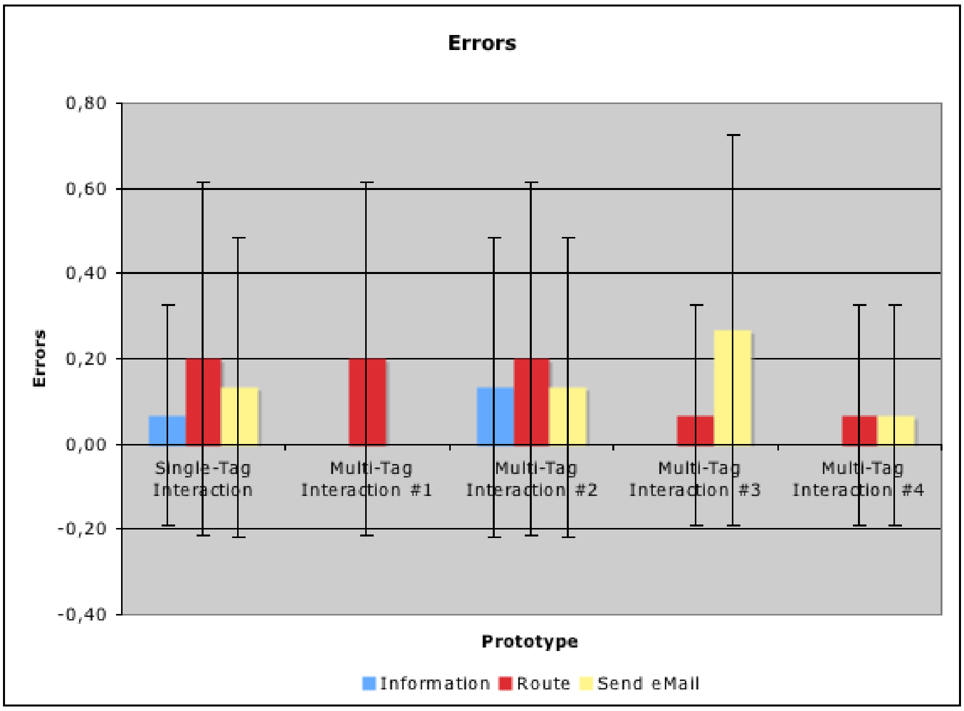

Figure 5.21: The mean and standard deviation of the errors for all five prototypes and all scenarios.

Consequently the Kolmogorov-Smirnov test turned out to be highly significant for all test cases and therefore no normal distribution can be detected.

Having a look at Mauchly's Test of Sphericity one can see that the test did not turn out significant for any of the two given independent variables ($p > .05$). Consequently the condition of sphericity is met and all conditions are equally related.

Most of the errors that occurred are based on one of three error types. Firstly some people had problems dealing with the radio buttons, which in fact have been modified checkboxes as already stated. In contrast to regular radio buttons, the user had to move the highlight and afterwards had to confirm his selection with the soft key in the middle. Unfortunately this was often forgotten by the users and caused a false selection. Especially the errors, which happend while using Single-Tag Interaction, where due to this fact.

The second error type was related to Multi-Tag Interaction #1 and Multi-Tag Interaction #2. The user had to confirm some selections (e.g. the sight in Multi-Tag Interaction #2) by pressing "Ok" before touching a tag and this was sometimes forgotten and therefore the tag was not accepted and the user had to go back and redo his selection.

The third problem occurred using the e-mail functionality. Some users thought that they need to add content to the e-mail and therefore additionally opened the information for the sight they wanted to use to mail and afterwards used the option "Send eMail".

Other problems, which occurred every now and then, but definitely much less than the previously mentioned three, have been users forgetting to select "Route" as option because they were just in full flow touching the tags. Furthermore there was some confusion when and how often to touch the "Route"-tag in the whole process of generating the route. Using Multi-Tag Interaction

#4, one user tried to touch the photo of the sight to select the sight and did not get immediately that both, sight and action, is selected touching only one tag.

Considering the exact values of the different tasks using Single-Tag Interaction, to get information led to a mean of 0,07 and a standard deviation of 0,26. For "Route" the mean is 0,20 and the standard deviation 0,41. At last sending an e-mail led to a mean of 0,13 and a standard deviation of 0,35.

Using Multi-Tag Interaction #1 the mean and standard deviation is 0,00 for the task "Information" and "Send eMail" because no mistakes have been made there. The option "Route" had a mean of 0,20 and a standard deviation of 0,41. "Information" and "Send eMail" also caused the exactly same mean and standard deviation using Multi-Tag Interaction #2 (m=0,13; sd=0,35). "Route" led to a mean of 0,20 and a standard deviation of 0,35.

During the usage of Multi-Tag Interaction #3 "Information" did not cause any errors (m=0,00; sd=0,00), carrying out the task "Route" led to one single error (m=0,07; sd=026) and "Send eMail" caused four errors all related to the above mentioned error of selecting information additionally (m=0,27; sd=0,46).

The last prototype, Multi-Tag Interaction #4, which caused the least number of errors compared to all other ones, had a mean and standard deviation of 0,00 for "Information". "Route" and "Send eMail" both led to a mean of 0,07 and a standard deviation of 0,26 each causing exactly one mistake.

All in all one can say that most errors occurred using the option "Route", which is not surprising since it asks for the longest interaction. "Send eMail" caused the second most errors, followed by "Information", which only caused very few errors.

Having a look at Anova's Within-Subjects Effects, no significance can be detected. Therefore one cannot for sure say that the rating was affected by the independent variables.

At last checking the Pairwise Comparison with Bonferroni Correction for design one cannot detect any significance. Therefore changing the design does not really effect the number of errors much, which is also shown by figure 5.21. In contrast Pairwise Comparison for the independent variable task shows significance for "Information" compared with the other two "Route" and "Send eMail". Anyway, the comparison of "Route" and "Send eMail" is not significant.

5.4.4 Execution Time

Execution time was recorded by the mobile application. The timer was started automatically during application's start and stopped after the last interaction step of every possible option ("Information", "Route" or "Send eMail"). The recorded times were stored in the midlet's RecordStore.

Looking at the results of the Kolmogorov-Smirnov and its Tests of Normality one can see that some are normally distributed and some not. The normally distributed ones are "Information" and "Route" using Single-Tag Interaction, "Send eMail" using Multi-Tag Interaction #1. "Information" using Multi-Tag Interaction #2, "Information", "Route" and "Send eMail" using Multi-Tag Interaction #3 and "Send eMail" using Multi-Tag Interaction #4.

Mauchly's Test of Sphericity was also applied. None of the results turned out to be significant. Consequently the condition of sphericity is met and all conditions are equally related to each other.

Figure 5.22 shows the means and standard deviations for execution time.

Generally one can see that "Route" was the longest task, followed by "Send eMail" and "Information". Furthermore Multi-Tag Interaction #2 turned out to be the slowest prototype, while Multi-Tag Interaction #4 was the fastest.

In detail, using Single-Tag Interaction led to the following results. "Information" with m=9970,27 and sd=2772,60, "Route" with m=33293,47 and sd=7580,26 and "Send eMail" with m=16709,13 and sd=6852,57.

Multi-Tag Interaction #1 and "Information" resulted in m=7913,60 and sd=5095,18, "Route" resulted in m=22562,40 and sd=10707,40 and "Send eMail" in m=12665,33 and sd=5024,31.

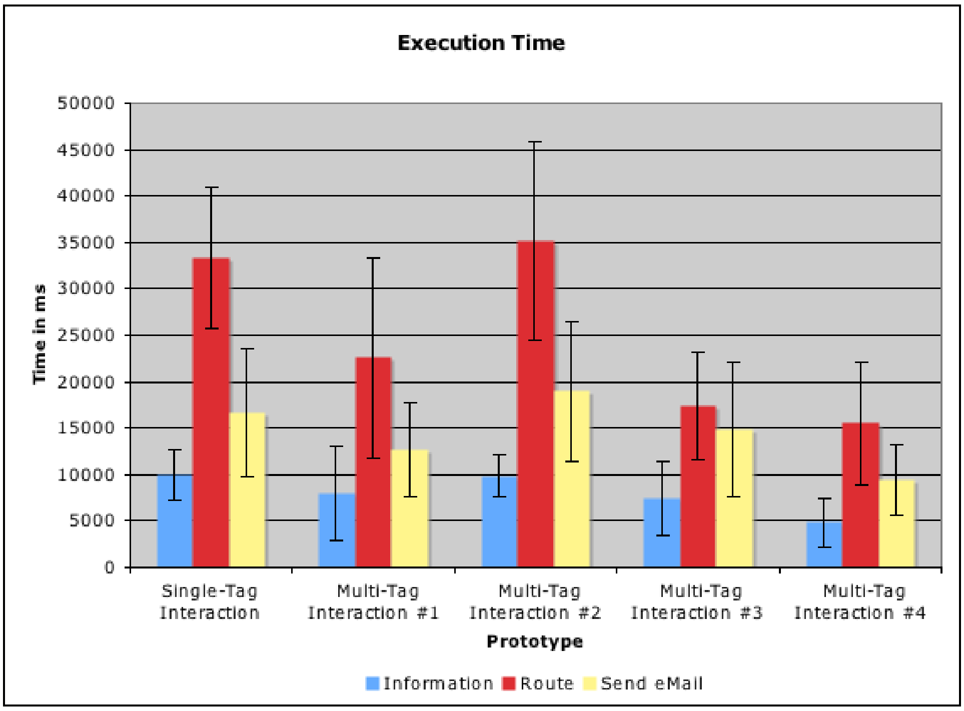

Figure 5.22: The mean and standard deviation of the execution time for all five prototypes and all scenarios.

Using Multi-Tag Interaction #2, the numbers for "Information" are m=9823,53 and sd=2235,87, for "Route" they are m=53102,33 and sd=10710,63 and for "Send eMail" they are m=18959,27 and sd=7470,22.

Multi-Tag Interaction #3 needed an execution time of m=7369,40 and sd=3978,49 for "Information", m=17389,07 and sd=5731,97 for "Route" and m=14880,47 and sd=7217,15 for "Send eMail".

The last and fastest prototype, Multi-Tag Interaction #4, led to m=4813,33 and sd=2640,45 for "Information", m=15523,80 and sd=6653,26 for "Route" and m=9450,67 and sd=3862,42 for "Send eMail".

Having a look at the Within-Subjects Effects of the repeated measure Anova for several independent variables, one realizes that all independent variables, design, task and the combination of design and task are significant (p<.001). Consequently the results for execution time are very significantly affected by all independent variables.

Pairwise Comparison with Bonferroni Correction showed that the combination of Single-Tag Interaction and Multi-Tag Interaction #2 as well as the combination of Multi-Tag Interaction #1 and Multi-Tag Interaction #3 and the combination of Multi-Tag Interaction #1 and Multi-Tag Interaction #4 and last but not least also the combination of Multi-Tag Interaction #3 and Multi-Tag Interaction #4 are not significant and therefore change between all those pairs does not cause a huge impact on the results. This is also recognizable when looking at figure 5.22 and the similar execution times for the above mentioned combinations. In contrast to the independent variable design, the independent variable task is significant in all cases (p<.000) and therefore changing the task in anyway has a significant impact on the execution time.

Keystroke-Level Model

Analog to the previous user study the Keystroke-Level Model [17] was applied to all prototypes and tasks to get a reference time. This led to the following results.

Looking at figure 5.23, which depicts the calculated and measured execution times for Single-Tag Interaction, one can see, that the values are quite similar. Therefore the Keystroke-Level Model meets the real times very well. The exact times can be seen in figure 5.23.

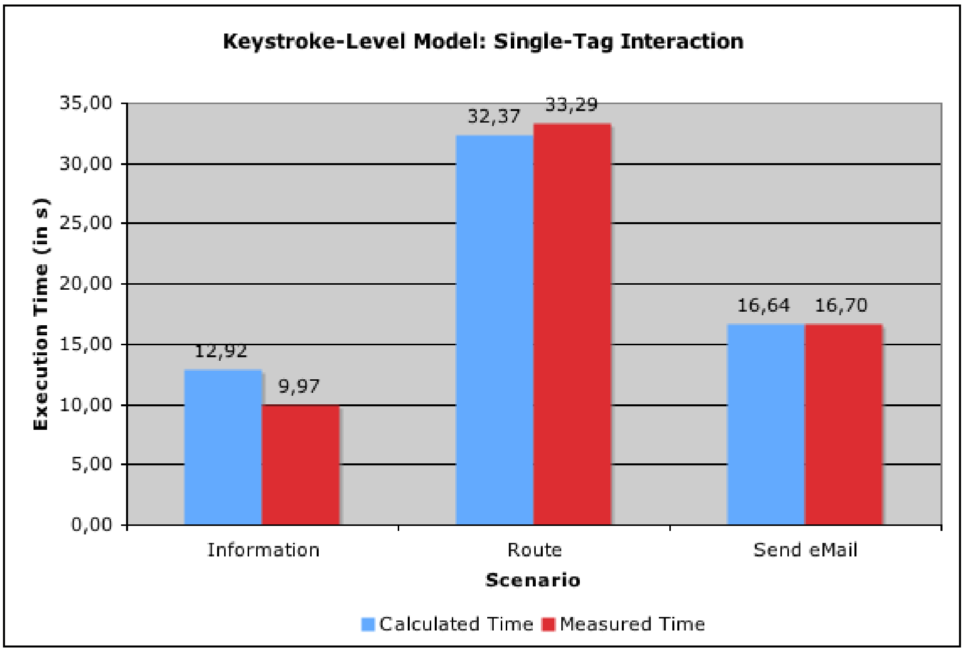

Figure 5.23: The calculated and measured times for Single-Tag Interaction.

Figure 5.24 shows the calculated time, the measured time and the calculated time with reduced attention shifts for Multi-Tag Interaction #1. Analog to the first user study one could observe that during the touching of consecutive tags, e.g. several tags for generating the route, the users carried out less attention shifts than assumed. Therefore the KLM was calculated again with the reduced number of attention shifts derived from the results of the user study. While this led to rather good results in the first user study, the calculated execution time with reduced attention shifts is still far away from the actual time (see "Route" in figure 5.24). Having a second look on the video analysis one can detect that many attention shifts are very short. Especially during the creation of the route. Users shot a very short glance on the mobile device but they did not think longer about their next interaction step. Generating a route and especially adding more sights to the route seems to be one "mental act" for the user. But the Keystroke-Level Model requests to place a "mental act" in front of each macro attention shift. Eliminating those "mental acts", which supposedly take 1,35 seconds each, one gets closer to the actual measured times. Further adjustments, which might be at order, are adjustments of the "pointing" parameter in the NFC action. Because generating a route, the user usually knows beforehand where the sights are located and as the user study showed the physical movement from tag to tag was faster than the assumed "pointing" time of 1 second. Anyway, with all those adjustments one has to keep in mind that those have not been evaluated but are mere observations from this certain use case and do only apply to the consecutive touching of tags, which strongly belong together during the execution of a task. Anyway, independent from this special use case another reason could be a shorter response time of the mobile device. The Keystroke-Level Model, as described in [17], was developed using the Nokia 3220 with an additional NFC shell. Compared to the Nokia 6131 NFC, which was used in all user studies described in this thesis, the Nokia 3220 is a very slow device. This might add to the difference between measured and calculated times in all scenarios, especially those who did not suffer from the effects caused by consecutive touching of tags.

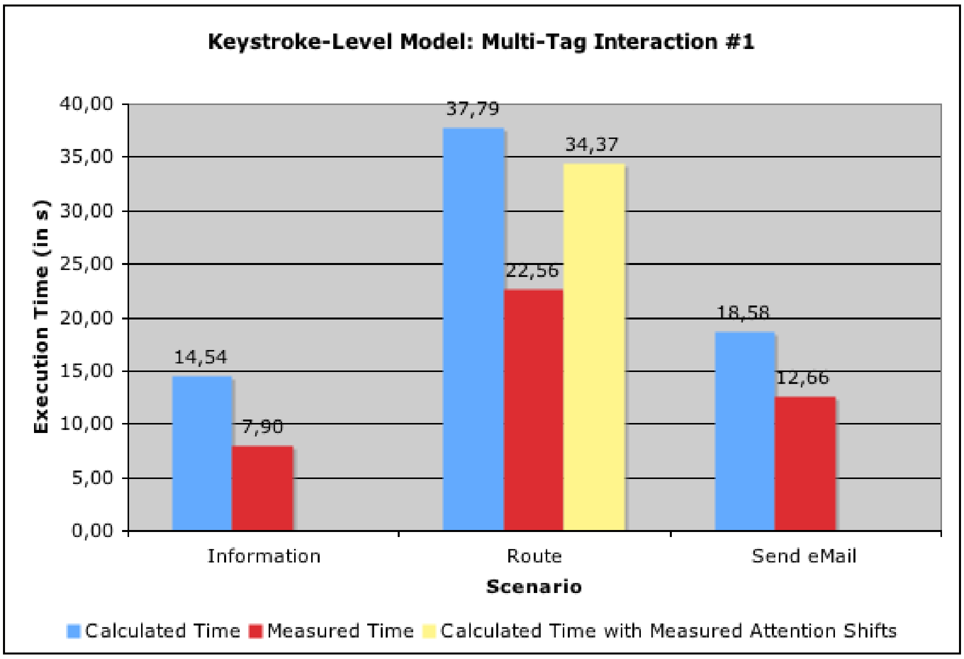

Figure 5.24: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #1.

Looking at the values of Multi-Tag Interaction #2 in figure 5.25, one can see that the calculated and measured times are close together similar to Single-Tag Interaction. Using Multi-Tag Interaction #2 much less tags need to be touched in comparison to the previous Multi-Tag Interaction #1. This supports the thesis that the calculation for touching tags is the cause for the inaccurate results using Multi-Tag Interaction #1.

Figure 5.26 shows the calculated time, measured time and calculated time with measured attention shifts for Multi-Tag Interaction #3. Similar to Multi-Tag Interaction #1 the values differ quite a lot. The possible reasons for that are the same as already mentioned for Multi-Tag Interaction #1. The number of "mental acts" might be to high and the time assumed for "pointing" as well. Additionally the system response time might be shorter using a newer mobile device than in the original KLM. Due to the fact that quite a lot of tags need to be touched using this prototype, these problems might add up and result in the big differences.

The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #4 are depicted in figure 5.27. Once again a big difference between calculated and measured times, especially concerning "Route", can be detected. Again the reasons might be the already depicted ones like the too high number of "mental acts", a too long assumed time for "pointing" and the faster mobile device. The results for this prototype also support the theory that the problems are related to the touching of tags, because the difference between measured and calculated times becomes bigger the more tags have to be touched during the execution.

5.4.5 Verifying the Hypotheses

As stated in section 5.3.1, three hypotheses have been established beforehand. Having analyzed the dependent variables one can confirm respectively confute them.

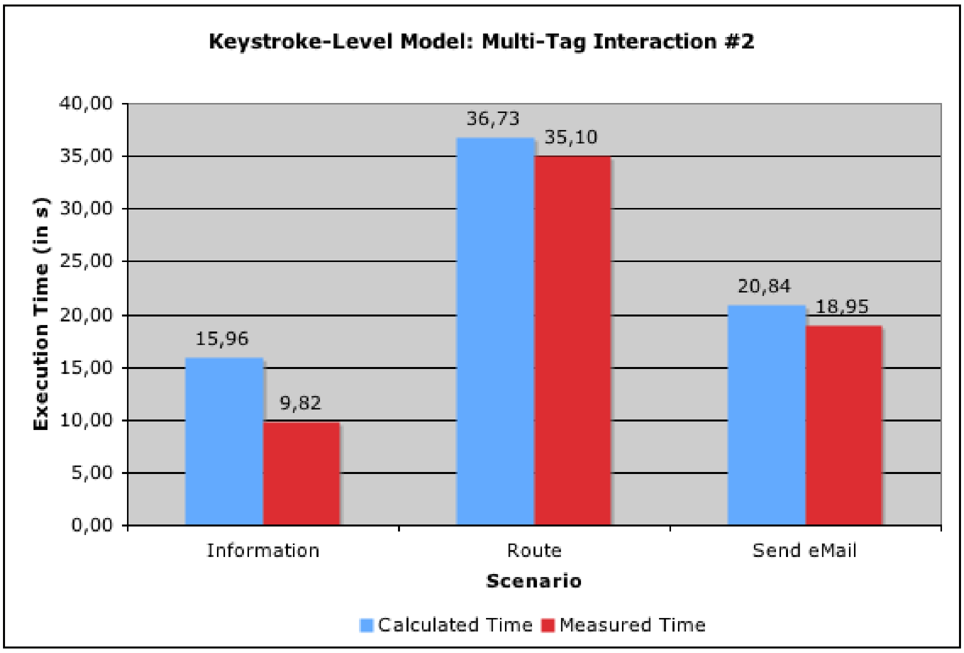

Figure 5.25: The calculated and measured times for Multi-Tag Interaction #2.

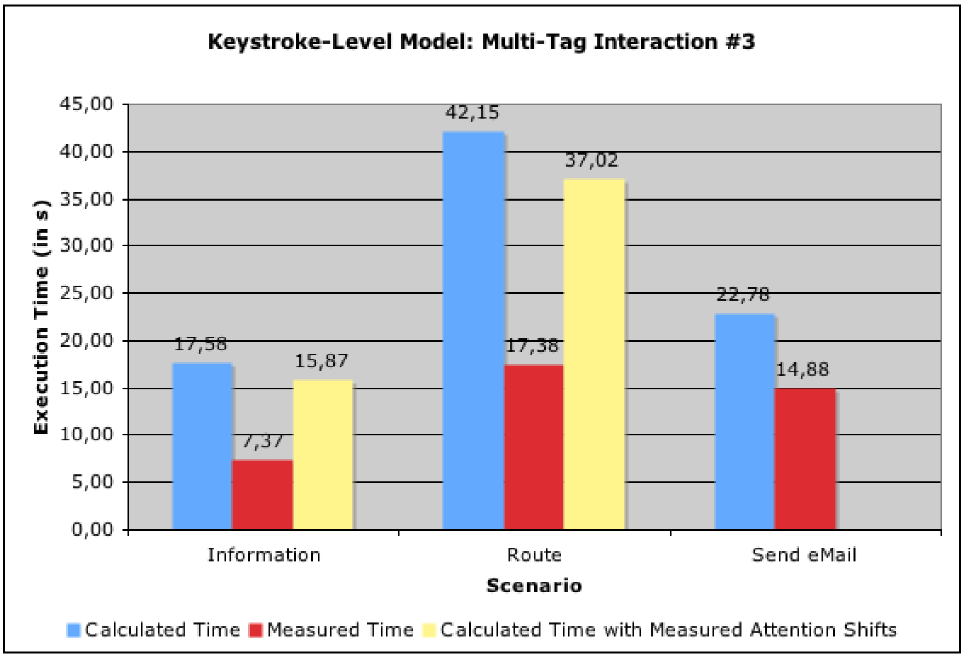

Figure 5.26: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #3.

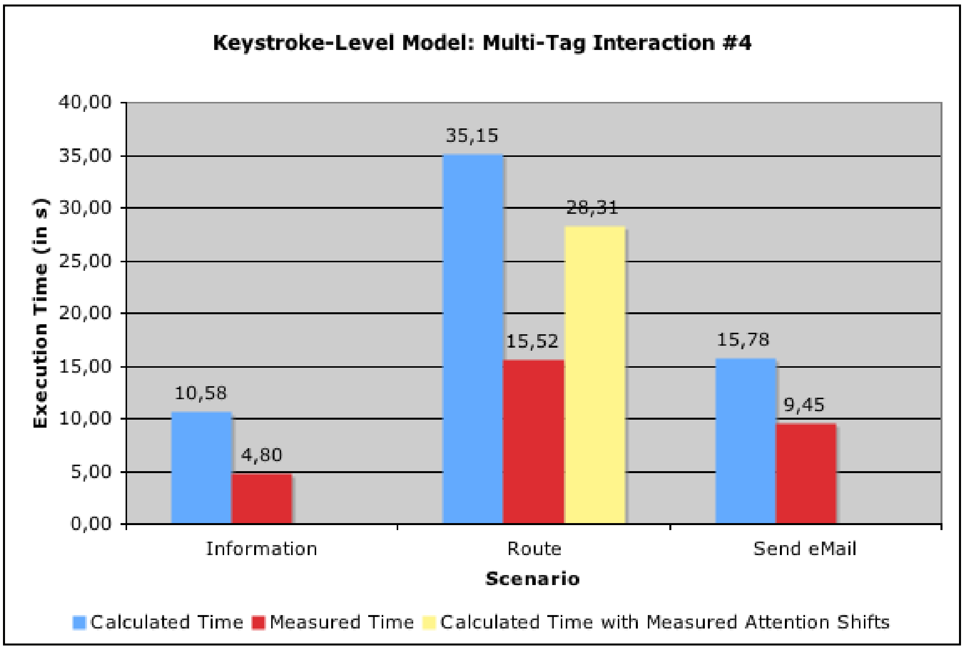

Figure 5.27: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #4.

Hypotheses number one cannot be confirmed completely. Single-Tag Interaction is indeed comparable slow but Multi-Tag Interaction #2 is even slower.

Consequently hypotheses number two also is confuted. Considering execution time Multi-Tag Interaction #2 is the slowest prototype. But anyway, except this, the prediction was correct for the other prototypes. In fact using Multi-Tag Interaction #4 the least errors occurred but all other prototypes led to about the same amount of errors. Concerning attention shifts the succession from least attention shifts to most attention shifts is Single-Tag Interaction, Multi-Tag Interaction #2, Multi-Tag Interaction #4, Multi-Tag Interaction and finally, with the most attention shifts, Multi-Tag Interaction #3.

The third hypotheses aims at qualitative data, which will be evaluated in more detail later on, but Multi-Tag Interaction #4 indeed was liked best but was very closely followed by Multi-Tag Interaction #3.

5.4.6 User Feedback

As already mentioned, beside the quantitive data some qualitative data has been collected with the help of several questionnaires. On the one hand each participant had to fill out a modified version of the IBM "Computer System Usability Questionnaire" (see appendix) after the usage of each prototype, on the other hand there was a closing questionnaire at the end of the user study to compare all presented prototypes. The goal of the questionnaires is to evaluate the overall acceptance of the application and the usage of Multi-Tag Interaction.

Modified IBM "Computer System Usability Questionnaire"

The modified version of the IBM "Computer System Usability Questionnaire" consisted only of eleven questions, which were derived from the nineteen questions of the original questionnaire. All questions were answered using a Likert scale ranging from -3 to +3 and an option "NA" in cases where the user did not feel able to answer a question. Furthermore free comment fields for positive comments about the prototype as well as for negative comments have been available. At last there was a comment field for any other remarks or suggestions.

Figure 5.28 shows the results for all eleven questions and all five prototypes.

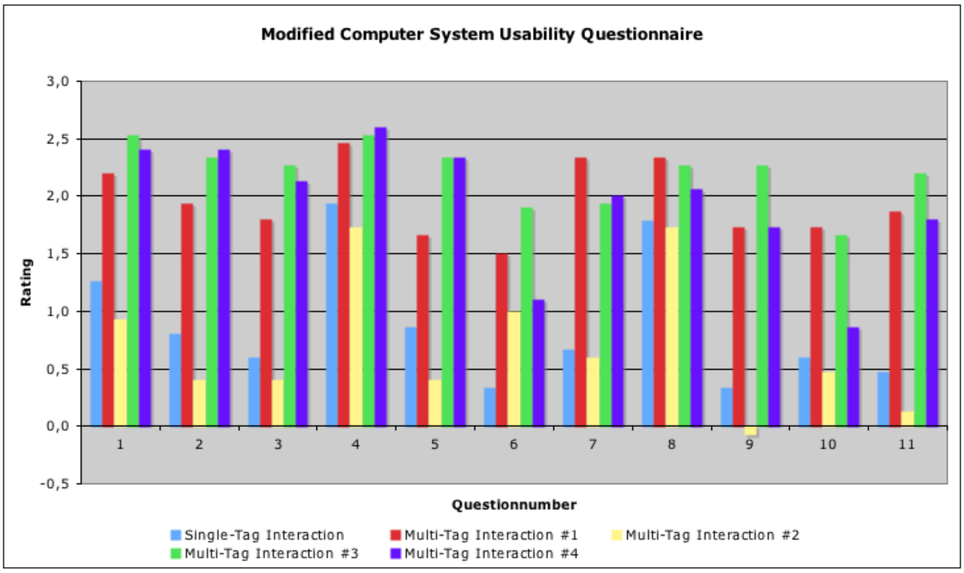

Figure 5.28: The results of the modified IBM "Computer System Usability Questionnaire".

Being asked how simple the usage of the design was Multi-Tag Interaction #3 got the highest rating with 2,5 followed closely by Multi-Tag Interaction #4 which got 2,4 and Multi-Tag Interaction #1 with 2,2. Single-Tag Interaction only got a rating of 1,3 and Multi-Tag Interaction #2 only got 0,9.

The second question asked how quickly the user was able to complete his work using the design. Multi-Tag Interaction #4 was rated as quickest with 2,4, closely followed by Multi-Tag Interaction #3, which got a rating of 2,3. Multi-Tag Interaction #1 also got a good rating with 1,9, whereas Single-Tag Interaction scored only 0,8 and Multi-Tag Interaction #2 even less with 0,4

Being asked about the efficiency to complete the work using the design, Multi-Tag Interaction #3 got the highest rating with 2,3. Multi-Tag Interaction #4 followed closely with 2,1 and Multi-Tag Interaction #1 with 1,8. The ratings for the other two have been pretty low with 0,8 for Single-Tag Interaction and 0,4 for Multi-Tag Interaction #2.

When asking whether it was easy to learn the usage of the design, the rating was quite good for all available prototypes, with 2,4 for Multi-Tag Interaction #4, 2,5 for Multi-Tag Interaction #1 and Multi-Tag Interaction #3, 1,9 for Single-Tag Interaction and 1,7 for Multi-Tag Interaction #2.

Becoming productive quickly seems to be true for Multi-Tag Interaction #3 and Multi-Tag Interaction #4, which both got a rating of 2,3. Multi-Tag Interaction #1 was rated with 1,7. Single-Tag Interaction only got 0,9 and Multi-Tag Interaction #2 got even less with 0,4.

Recovering from mistakes is supposed to be easy and quick using Multi-Tag Interaction #3, which got a rating of 1,9, followed by Multi-Tag Interaction #1 with 1,5. Multi-Tag Interaction #4 got 1,1, Multi-Tag Interaction #2 got 1,0 and Single-Tag Interaction only got 0,3.

The organization of the information on the mobile interface is quite clear using Multi-Tag Interaction #1, which was rated with 2,3. Multi-Tag Interaction #4 got 2,0. closely followed by Multi-Tag Interaction #3 with 1,4. Single-Tag Interaction got 0,7 and Multi-Tag Interaction #2 got 0,6.

Concerning the organization of information on the physical interface all prototypes got good ratings. Multi-Tag Interaction #1 got 2,3 as well as Multi-Tag Interaction #3. Multi-Tag Interaction #4 was rated with 2,1, Single-Tag Interaction with 1,8 and Multi-Tag Interaction #2 with 1,7.

Asked whether they liked using the interface of the design. Multi-Tag Interaction #3 got the highest rating with 2,3. Multi-Tag Interaction #1 and Multi-Tag Interaction #4 both got a rating of 1,7 whereas Single-Tag Interaction got a rating of only 0,3. Multi-Tag Interaction #2 was detested by nearly all users and got an overall rating of -0,1.

Only Multi-Tag Interaction #1 and Multi-Tag Interaction #3 more or less seem to have all expected functions and capabilities and got both a rating of 1,7. Multi-Tag Interaction #4 was rated with 0,9, Single-Tag Interaction with 0,6 and Multi-Tag Interaction #2 with 0,5.

At last the users where asked about their overall satisfaction. Multi-Tag Interaction #3 got the highest rating with 2,2 followed by Multi-Tag Interaction #1 with 1,9 and Multi-Tag Interaction #4 with 1,8. Single-Tag Interaction only got 0,5 and Multi-Tag Interaction #2 even less with 0,1.

Some positive as well as negative comments that have been made concerning all or at least more than one of the five prototypes.

At first the e-mail functionality was the cause of confusion in many cases. Besides some problems caused by the implementation like the missing feedback on the mobile device about which sight one is sending an e-mail, or that there is no possibility to send information about more than one sight, users generally had a different mental model of the action than the one that was implemented. They always wanted to add some kind of content to the e-mail e.g. by additionally touching the information-tag. The idea that the e-mail was generated completely by the mobile application, without them ever seeing what was sent, led to some discomfort.

The missing option to correct a route by deleting an already selected sight also was criticized by many users. Using the prototypes one had to start from the beginning if one selected a sight, which one did not want to be part of the route.

Furthermore users expressed concerns about the fact that they either had only a list of sights or they had only tags on the map. The first implementation might cause problems for users who do not know the name of a certain sight but know where it is or how it looks. The second approach might be time consuming if a user knows the name of the sight but has no idea where the sight is in Munich and has to search for it on the map. This especially becomes a problem if more than seven sights are available on the map. Generally one can only place a limited number of sights on the map.

Some users questioned the start-tag and its benefit for the overall application. They are happy to start the application on their mobile device. One user generally disliked submenus, which have been part of all prototypes that did not offer tags for actions. Furthermore the remodeled checkboxes, which were supposed to act as radio buttons were not enjoyed by all users.

All in all there also have been problems dealing with the NFC technology. Some subjects needed quite some time until they were able to read a tag on their first try. One user pointed out that it takes him too long until he gets the information from one tag.

Negative comments about Single-Tag Interaction have been that the usage of NFC is no real benefit when starting the application is the only feature, which is realized using the NFC technology. Consequently the number of key presses is very high, which might lead to more errors as one user expected. But this could not be proven by the results of the user study. Furthermore users complained that the right soft key as well as the middle soft key were used to confirm an action. Generally there is a very distinct difference. The soft key in the middle was only used when confirming the selection of a radio button. In all other cases the right soft key was used. Anyway, this caused confusion. Users missed the back function in some cases. After having selected an option they were forced to go through the whole action. Moreover users pointed out that the benefit of the map was that one does not have to know the name of a certain sight, but since there are no tags available at the sights this benefit is kind of lost because at first one has to find out the name on the map and afterwards has to find the name in the list on the mobile device. Generally navigation sometimes was said to be uncomfortable and cumbersome, which led to the impression that task execution took a rather long time, which is true as the user study showed. One user compared it to sending a text message: "it is terrible but it works". Positively it was mentioned that the user feels in control due to the fact that one uses normal, already known functionality of the mobile device.

Using Multi-Tag Interaction #1 negative comments have been that one was forced to look for the sights on the map, even though this was also mentioned as big advantage. Furthermore creating a route was confusing for one participant because he had the impression that the selection of the first sight was done differently than the selection of the additional sights. Of course there have also been positive comments. Generally it was considered as simple and fast. Some users pointed out that the physical interaction was applied exactly right by using it to select the tags. Furthermore it made it really easy to switch between different sights. The fact that actions have been selected by the usage of the mobile interface and its soft keys gave users an additional feeling of being in control.

All in all Multi-Tag Interaction #2 was not liked that much by the users and therefore quite a lot negative comments have been made. They considered the interaction with this prototype as cumbersome, not intuitive and time consuming. The navigation was confusing because of the permanent switching between the poster and the mobile device in an unexpected way. Having selected the sight on the mobile device and seeing the corresponding photo on the mobile device's display caused an irritating moment for many users, in which they are wondering what they are supposed to do next. Some feel that the selection of the action using the submenu on the mobile device is faster. Generally the images on the map gave the user the impression they could touch them, although there was no NFC-symbol attached to them. Anyway a positive remark that has been made was directed at the big area one can touch to select an action. This makes the aiming easier.

Using Multi-Tag Interaction #3 the users were free to either choose the sight or the action first. In about 50% of all test cases the user decided to select the action first. All users, who at least one time selected an action before the object chose to select "Route" before selecting a sight. In case a user selected the action before the object two times he always choose to select "Information" and "Route". Four users selected action as first item during all three tasks. Anyway the switching between different actions was confusing for some users, because if a sight was previously selected, the sight was combined with the new action even if there has already been carried out an action with this sight. Still, Multi-Tag Interaction #3 was very much liked by the participants. They considered it to be easy due to the very limited input with the keypad and the fact that no additional menus were part of the mobile application. They had the feeling that they made less mistakes, which is partly true. During the conduction of the user study five mistakes were made using this prototype. But four of this mistakes were related to the e-mail functionality, which was confusing and led users to additionally touch the information-tag. This was not necessary but did not interrupt the workflow, therefore it was not experienced as mistake by the users. All in all many users claimed to like the freedom of choosing either a sight or an action as first item.

Multi-Tag Interaction #4 was also quite well accepted by the users. Anyway some negative remarks have been made. At first, using "Route", some users were confused, which tags they should select for adding further sights to the route. Actually all tags were possible, because the mobile application was in the routing mode and therefore only extracted the sight of each tag and ignored the action. Furthermore some pointed out that the photos of the sights cannot be seen anymore on the mobile device's display. But as one pointed out correctly, they still are part of the tag-enhanced map. At last some users complained that the map contained too many tags, which was rather confusing because the arrangement was not that clear anymore. Furthermore that led to the problem that the tags were closer together and therefore the aiming of the mobile device was harder. But despite the prior mentioned problems the usage of Multi-Tag Interaction #4 is supposed to be simple, quick, efficient and intuitive.

Closing Questionnaire

The closing questionnaire (see appendix) aimed at the comparison of the five prototypes.

Therefore in the first question the users have been asked, which prototype they liked best. Multi-Tag Interaction #4 was named the most (6 users) but Multi-Tag Interaction #3 followed very closely (5 users). Multi-Tag Interaction #1 was named three times and Single-Tag Interaction was named by one user, where as Multi-Tag Interaction #2 was never selected. Reasons for choosing Multi-Tag Interaction #4 have been the easy selection, especially concerning the route and the fact that one does not need to make a lot of input using the keypad. Furthermore Multi-Tag Interaction #4 was considered very fast, which also was verified by the user study. Users who chose Multi-Tag Interaction #3 stated that they considered it to be quick and easy. They liked the freedom to choose either the action or the sight first and that they did not have to shift their attention all the time. Furthermore the big areas for choosing the action were remarked positively. Having chosen Multi-Tag Interaction #1 they stated that they enjoyed selecting the action on the mobile device because it gives them a feeling of being in control and they considered it to be fast. Furthermore, especially if many people are standing in front of the map the interaction with the map is minimized. The last comment was also the reason for one user to choose Single-Tag Interaction. He feared that it would just not be practical to put up such a map and have more than one person interact with it at the same time.

The second question asked, which prototype was the least suitable design. Ten participants (66%) chose Multi-Tag Interaction #2. As reasons they stated that they considered it to be slow, cumbersome and very unintuitive. Although they were forced to shift their attention in the other prototypes as well, they were especially bothered by it using this prototype. It just felt wrong to them to select the sight on the mobile device but the action on the mobile application. Especially since the sight selection consisted of a long list on the device and wanting to generate a route they had to undergo this selection process four times. Four people named Single-Tag Interaction as their least favorite design. They detested that they had to carry out everything using the keypad and as one stated the "cool technology" is totally lost. Two times Multi-Tag Interaction #4 was named and one time Multi-Tag Interaction #3. The reason for both was the fact that the users considered them to have too many tags. Multi-Tag Interaction #1 was not named by anyone.

Being asked which interaction style - on the mobile device, on the tag-enhanced poster, or a combination of both - they favored. Eight participants preferred interaction with the poster only. Reasons for that are that it is considered to be easy and quick. It reduces attention shifts and minimizes input with the help of the keypad but instead offers bigger areas to make one's selection. Five participants preferred a combination of tag-enhanced posters and interaction with the mobile device itself. Advantages that they see in this interaction style are the fact that the poster does not suffer from information overload and all in all there is more flexibility in designing the whole application. Two users voted for mobile device only. The reasons were that no additional knowledge of the NFC technology is necessary and everybody can interact in the usual and known way. Furthermore more people can use the application at the same time, which might be a problem if all users want to access the same tags at once.

Multi-Tag Interaction #3 offered two different kind of tags, tags for sights and tags for actions, which could be combined. In contrast, Multi-Tag Interaction #4 offered three tags for each sight, which already stored the combined information of sight and action. Being asked, which way they preferred the users overall are undecided. Eight participants chose the already combined tags whereas seven users voted for the separate tags, which they have to combine themselves. Reasons for the combined tags have been that one has to touch less tags and does not have to remember the order in which they are supposed to be touched. They considered it to be faster and more clearly arranged because it is evident on the first glance, which options are available. Users who chose separate tags to be combined preferred that they can make their selection step by step e.g. choosing a sight first and afterwards deciding which action to perform. Furthermore the hierarchical structure reduces the number of tags and therefore it is less confusing.

The next question split the whole interaction in different parts and was asking, which interaction style - using the mobile interface, the poster or both - the user would prefer for carrying out this part of the interaction. Six people preferred starting the application with the help of the start-tag on the poster. Five users preferred starting with the mobile device and four did not care one way or the other. Selecting objects, ten participants preferred the tag-enhanced poster, three liked both and two wanted to use the mobile application to select them. Concerning the selection of the actions, it is different. Eight people prefer the selection with the help of the mobile application, four chose the poster and three liked both. Having to combine both, objects and actions, eight participants would prefer to select everything on the poster, four like both possibilites and three prefer the mobile device, which actually is a little contradiction concerning the two questions beforehand, which give the impression that the combination of sights with the help of the poster and action with the help of the mobile application, consequently a combination using both, is the preferred choice. Being asked about the final input in an interaction process, e.g. "generate" using the route, eleven participants want to use the mobile application whereas two voted for the poster and further two liked both possibilities. Considering correction eleven participants want to carry them out using the mobile device, two want to use the posters and further two can imagine both. According to seven participants additional help should be given on the mobile device, five want it on the poster and three like both solutions.

Being asked how intuitive the combination of objects and action is, users said that it was mostly good. Different ideas have been given about the placement of some information on the handling of the prototype and the combination. Some suggested placement on the poster because there is more space but one could only offer a general information and no hints about the current status of the application unless a dynamic display is used. Others preferred a hint on the mobile device's display directly with every interaction step. Another idea suggested by several users was the introduction of a tutorial tag, which can be touched in case of questions and offers help on the mobile device's screen.

Problems that occurred during the execution of the tasks have been, mainly based on the whole design of Multi-Tag Interaction #2, which was absolutely not intuitive for the users because the distribution of actions and objects between the poster and mobile application was confusing. Furthermore the fact that two different buttons were used as "Ok"-buttons using Single-Tag Interaction was mentioned. In general the usage of the radio buttons was a problem and last but not least, the rather huge number of tags on some posters, especially using Multi-Tag Interaction #4 caused information overload for some users.

Suggestions and further comments on the prototypes have been a clear arrangement of the buttons, especially concerning "Ok". Furthermore the by now often mentioned problem with the radio buttons should be solved e.g. having to confirm the selection and the highlight, which always starts at the top and not at the currently selected item. And last but not least, users requested that the application recognises the tags immediately and not only after having touched the start-tag.

6 3rd User Study: GUI Widgets

The goal of the third user study is to refine the first one. Consequently the third user study also evaluates "Selection" and "Navigation" but the main focus is on "Selection". In the first user study all selection on the mobile device was based on radio buttons. In this follow up study more GUI widgets are taken into account.

6.1 Basic Use Case

The use case is derived from online search forms for book searches in libraries. In this case, the user has a mobile device, the Nokia 6131 NFC, which offers an application, to search for books by filling out different elements in a form.

The basic use case is shown in figure 6.1. Having started the application a welcome screen with some basic instructions about the application is presented to the user. Afterwards four sections have to be filled out. The search parameter consists of the options author, title and keyword. Afterwards the user is supposed to type in his search phrase into a text field. In the third section the user needs to choose his desired mediatypes from four options: book, journal, magazine and CD/DVD. The last section is library where the user is supposed to choose the library in which he wants to look for the book. Possible options are "Uni-Bibliothek", "Studentenwerks-Bibliothek" or "Bayrische Staatsbibliothek". After having selected everything the user is supposed to submit the search and will be presented the search results on his mobile phone's display.

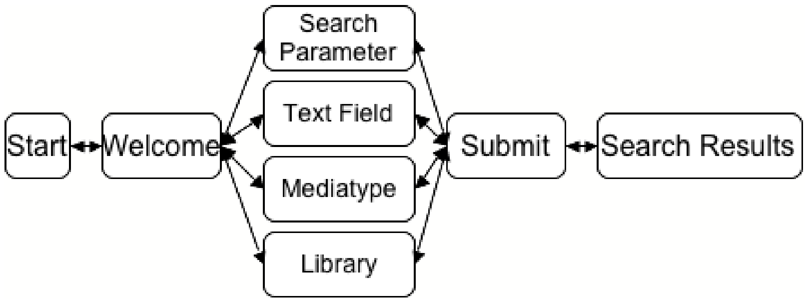

Figure 6.1: The basic workflow of the tasks belonging to the third user study.

All in all there are three different prototypes, which all offer the possibility to complete the task. All three consist of a mobile application as well as a tag-enhanced poster whereas the placement of the widgets for selection differs between those prototypes. Sometimes the user carries out the selection on the mobile device itself, sometimes he needs to physically interact with the poster. Single-Tag Interaction offers a solution for the task by placing everything, selection as well as navigation, on the mobile device. Multi-Tag Interaction #1 offers tags for navigation but selection is still carried out directly on the mobile device. Multi-Tag Interaction #2 places everything on the tag-enhanced poster meaning selection and navigation is carried out using tags. There is no prototype for the possible combination of selection on the poster and navigation on the mobile device, because as already mentioned the focus in this user study is on selection, and both possible distributions for selection using multi-tag interaction are evaluated by the already existing prototypes. Figure 6.2 shows the distribution of elements on the mobile device and the poster.

6.1.1 Single-Tag Interaction

In figure 6.3 one can see the tag-enhanced poster for Single-Tag Interaction. As already hinted at by the name of the prototype, there is only one tag to start the application. All further interaction is carried out directly on the mobile device.

Selection \ Navigation	Handy	Poster
Handy	STI	MTI #1
Poster	---	MTI #2

Figure 6.2: All available combinations of "Navigation" and "Selection" distributed on the mobile application and the physical interface.

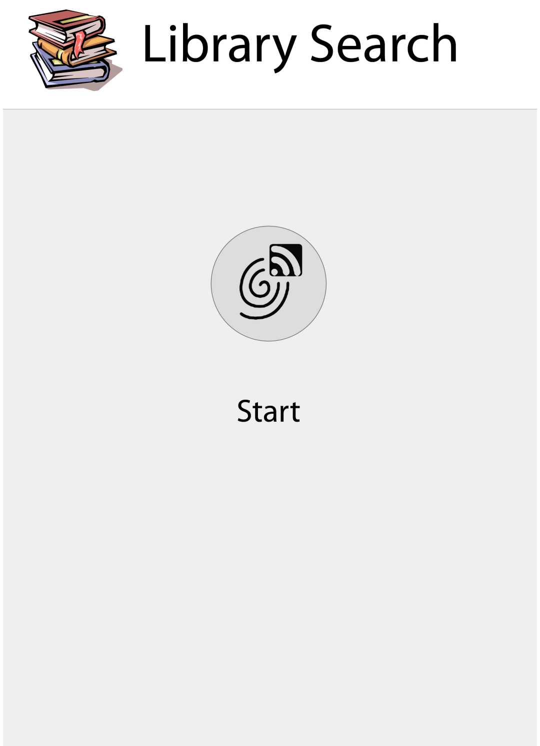

Figure 6.3: The tag-enhanced poster for Single-Tag Interaction consisting of one single tag, which starts the application.

The mobile application is depicted in figure 6.4. Having started the application by touching the tag the user is presented the startscreen (a). After pressing "Ok" he will see a form consisting of different GUI widgets (b). Search parameter is implemented using a drop-down followed by a text field for the search phrase. Afterwards checkboxes are used for the mediatype, which of course makes it possible for the user to select more than one item. The library options are offered using radio buttons and therefore only one library can be selected. Having filled out everything the user can press "Submit" and the search results will be presented to him (c).

Figure 6.4: The mobile application belonging to Single-Tag Interaction.

6.1.2 Multi-Tag Interaction #1

The physical interface of Multi-Tag Interaction #1 is shown in figure 6.5. It consists of a start-tag, which launches the application. Afterwards the user can jump to the different categories by touching the tags for search parameter, text field, mediatype and library. The actual selection for every category will be done using the mobile application. The optical design of the tags for mediatype, which are surrounded by a square in contrast to the circles around the other tags, indicates that mediatypes are selected using checkboxes and therefore more than one mediatype can be selected. Having chosen everything, the submit-tag will submit the search and show the user the search result.

Figure 6.6 and 6.7 show the mobile application for Multi-Tag Interaction #1. After touching the start-tag the user sees the startscreen (a) with a short introduction. Touching the different tags for search parameter, text field, mediatype and library the user will jump to the different screens (b to e) to select his choice analog to the first prototype. The main difference is that the GUI widgets are separated on different screens. After each selection, which has to be confirmed by pressing "Ok", a summary of the already selected items is shown (f). After submitting with the help of the submit-tag the user gets the search result, which looks exactly the same as in the application for Single-Tag Interaction, which is depicted in 6.4.

6.1.3 Multi-Tag Interaction #2

The tag-enhanced poster of Multi-Tag Interaction #2, as shown in figure 6.8, offers every selection as tag as far as possible. The only exception is the text field. Offering 26 tags for every letter to put in the search phrase does not seem very practicable, therefore the text field tag leads to a text input field on the mobile device (screen (b) in figure 6.9). Furthermore the tags for mediatype are surrounded by squares indicating that more than one item can be selected in this category. Analog to the previous prototype there is a start- as well as a submit-tag.

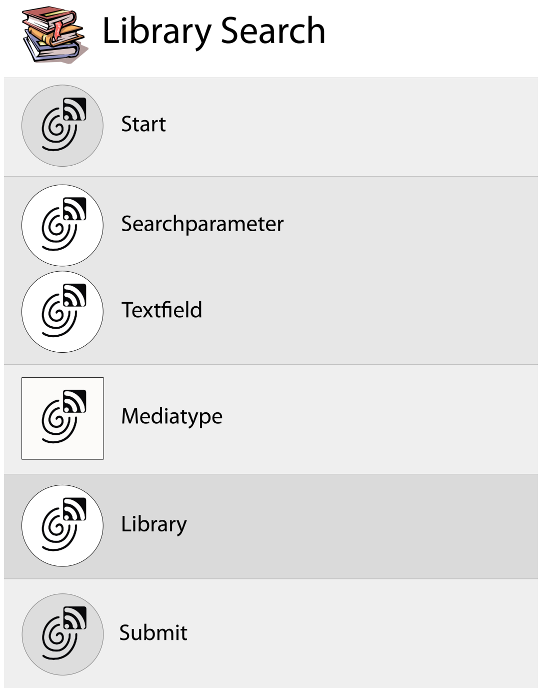

Figure 6.5: The tag-enhanced poster for Multi-Tag Interaction #1 consisting of a start-tag, tags for each category and a submit-tag.

Figure 6.6: The first part of the mobile application belonging to Multi-Tag Interaction #1.

Figure 6.7: The second part of the mobile application belonging to Multi-Tag Interaction #1.

Figure 6.8: The tag-enhanced poster for Multi-Tag Interaction #2 consisting of a start-tag, tags to make the selection for each category and a submit-tag.

Figure 6.9 shows the screens, startscreen, text input and summary, of the mobile application of Multi-Tag Interaction #2.

Figure 6.9: The mobile application belonging to Multi-Tag Interaction #2.

Corrections are handled differently depending whether only one item can be selected in a category or more than one. Consequently search parameter and library can be changed just by touching another tag from the same category. Concerning mediatype the user will add the item to the previous selected one by touching another one from the same category. To remove an already selected item, one has to touch the item again.

Feedback, which items are selected, is given on the mobile device's display, which shows a summary (c) of all already selected items.

After having touched submit, the search results are presented analog to the previously described prototypes.

6.2 Implementation

Analog to all previous studies the prototypes for the third user study are running on the Nokia 6131 NFC and consist of a mobile application and a tag-enhanced poster. Both will be shortly described in the following.

6.2.1 The Mobile Application

The only difference concerning the implementation of the third prototype is based on the optical appearance. Instead of J4ME [7], which was used for the graphical user interface of the previous prototypes, the basic Java ME is used for the optical appearance of this application. This is decided even though this results in the fact that one is limited in the placement of the soft keys. The goal of this user study is to test different GUI widgets, like drop downs or checkboxes, and Java ME offers more GUI widgets than J4ME.

All in all four different widgets are tested with the prototype. The option search parameter is implemented using a `ChoiceGroup` with the `choiceType Choice.POPUP`, which leads to a drop down or combo box. The second GUI widget is a text field, which is intended for the search phrase. The option mediatype is created using a `ChoiceGroup` with the `choiceType Choice.MULTIPLE` offering checkboxes for all available mediatypes. The last GUI widget are radio buttons for the option library, which are also implemented using a `ChoiceGroup` with the `choiceType Choice.EXCLUSIVE`.

As already stated, the only change concerning technical aspects is the switch to Java ME for the GUI. Consequently all necessary methods concerning NFC interaction are part of the prototype, too, as well as the basic Java ME structure for the remaining program logic.

6.2.2 The NFC-Enhanced Poster

Concerning the tag-enhanced poster, there is no technical difference compared to the previous ones described in 4.2.2 and 5.2.2.

The posters are enhanced with Mifare Standard 1k NFC tags. They either support the PushRegistry and act as start-tag or they just contain plain text, which can be read by the application.

6.3 User Study Design

The third user study refines the first user study and once again evaluates the multi-tag interaction categories "Selection" and "Navigation" but with the focus on selection with the help of GUI widgets. Still the goal of the evaluation is to find out, which distribution of information, on the mobile device or the physical interface, is the most enjoyable, error tolerant and efficient.

6.3.1 Experimental Design

In the following some thoughts on the basic design of the user study will be presented.

Hypotheses

The following hypotheses have been established before carrying out the user study.

- H1: Single-tag interaction is slower compared to all designs for multi-tag interaction.
- H2: Performance regarding task completion time and number of errors improves from single-tag interaction to multi-tag interaction in the following order: Single-Tag Interaction, Multi-Tag Interaction #1, Multi-Tag Interaction #2

Independent Variables

Two independent variables are tested in this user study: design and task complexity.

Design consists of three levels, the three prototypes, Single-Tag Interaction, Multi-Tag Interaction #1 and Multi-Tag Interaction #2, which already have been described in detail in section 6.1.

The second independent variable is task complexity and consists of two levels, low task complexity and high task complexity. Those two levels are represented by the following two scenarios, which all participants have to carry out with every prototype.

1. Low task complexity:

   You want to find the book "Java ist auch eine Insel" with the help of the application "LibrarySearch". In the following you type into the search form.

   - *Search parameter: Keyword*
   - *Text field: Java*
   - *Mediatype: Book & CD/DVD*
   - *Library: Studentenwerks-Bibliothek*

2. High task complexity:

   You want to find the book "Java ist auch eine Insel" with the help of the application "LibrarySearch". In the following you type into the search form.

   - *Search parameter: Keyword*

- *Text field: Java*
- *Mediatype: Book & CD/DVD*
- *Library: Studentenwerks-Bibliothek*

Before you submit your search you are modifying your search as follows:

- *Search parameter: Title*
- *Mediatype: Book*
- *Library: Uni Bibliothek*

Dependent Variables

The third user study measures exactly the same independent variables as the first two: execution time, number and kind of errors and number of attention shifts.

Execution time is automatically measured by a timer, which is implemented in the mobile application and stores everything in the RecordStore.

Additionally, analog to both previous studies, the execution of the user study is taped on video for an afterward video analysis, which offers the possibility to count the attention shifts as well as refining the notes about errors or additional comments of the users, which are already made during the actual execution of the study.

Latin Square

Once again the study was based on a within subjects or repeated measures experimental design [10] including all advantages and disadvantages as described in 4.3.1. Consequently a latin square design was used as basis of this user study. The whole study is based on a multivariate design with two independent variables: design and task complexity.

The latin square for the variable design, which has three levels, is depicted in figure 6.10. The three levels are of course the three prototypes Single-Tag Interaction, Multi-Tag Interaction #1 and Multi-Tag Interaction #2.

Order of Design		
Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2
Multi-Tag Interaction #2	Single-Tag Interaction	Multi-Tag Interaction #1
Multi-Tag Interaction #1	Multi-Tag Interaction #2	Single-Tag Interaction

Figure 6.10: Latin square for the independent variable design.

The second variable, task complexity, only has two levels, low and high task complexity. Therefore those two conditions will be alternated. Hence figure 6.11 shows the combination of the two independent variables for the first participant. He is supposed to start with Single-Tag Interaction and low task complexity, followed by high task complexity and afterwards moves on to Multi-Tag Interaction #1.

	#1	#2	#3
Design	Single-Tag Interaction	Multi-Tag Interaction #1	Multi-Tag Interaction #2
Task	Low Task Complexity	High Task Complexity	Low Task Complexity
Task	High Task Complexity	Low Task Complexity	High Task Complexity

Figure 6.11: Latin square for the first participant.

6.3.2 Conducting the User Study

Due to the fact, that this user study was conducted together with the second user study, the same fifteen participants took part. Since fifteen is divisible by three, this fits perfectly with the latin square design.

Analog to the previous two user studies, after having been asked for the permission to record the user study on tape, the participant is asked to fill out the demographic questionnaire (see appendix), which asks for some basic data and technical background.

Afterwards the user will carry out all tasks with all prototypes in the latin square required order. Generally at first the user gets a short introduction and has the possibility to try out the features of the prototype before conducting the actual task.

Following, after having finished all tasks with one prototype, he is asked to fill out the modified IBM "Computer System Usability Questionnaire" (see appendix). Afterwards he is supposed to go on with the next prototype until he finishes all three and is asked to fill out the closing questionnaire (see appendix), which compares all presented prototypes.

Figure 6.12 gives some impressions from the conduction of the second user study.

Figure 6.12: Conducting the user study. Subjects using the prototype Multi-Tag Interaction #1 and typing "Java" into the text field, submitting the search and filling out the modified IBM questionnaire.

6.4 Evaluation of the User Study

Analog to the two previous user studies, all collected data concerning the dependent variables, attention shifts, errors and execution time is evaluated using SPSS [9]. Kolmogorov-Smirnov is used for the analysis of the normal distribution. Furthermore a repeated measure Anova is executed. Finally all qualitative data is summarized.

6.4.1 Demographics and Technical Background

The second user study was executed together with this user study. Meaning the same participants had to test both prototypes, MunichCityGuide and LibrarySearch. To eliminate learning effects, the order of the prototypes was alternated, some starting with MunichCityGuide and some with LibrarySearch.

Anyhow, since the participants have been the same, concerning demographics and technical background everything stated in section 5.4.1 also applies to this user study.

6.4.2 Attention Shifts

Analog to the previous two user studies only macro attention shifts between the mobile device and the physical interface are evaluated by using video analysis.

The Kolmogorov-Smirnov shows in its Test of Normality that, as far as one is able to apply it, the results are not normally distributed because all significance values are below 0,05. Once again the test cannot be applied to all tasks, which caused a constant number of attention shifts throughout all participants.

Mauchly's Test of Sphericity could not be applied to the independent variable task complexity because task complexity consists only of two levels and Mauchly's Test of Sphericity can only be applied to variables, which offer at least three levels. Anyway, for the independent variable design and the combination of design and task complexity the test turned out significant. Consequently the condition of sphericity is not met and some conditions are more related than others.

Figure 6.13 shows all means and standard deviations for the three prototypes and both tasks. Single-Tag Interaction, as usual, only caused one attention shift from every user (m=1,00; sd=0,00) independent of the task.

Multi-Tag Interaction #1 was supposed to lead to a constant number of attention shifts, too, but due to some errors this was not achieved for high task complexity (m=16,27; sd=0,70), whereas low task complexity caused a constant number (m=10,00; sd=0,00).

Using Multi-Tag Interaction #2, a series of tags had to be touched without any necessary interaction on the mobile interface. This leads to a different number of attention shifts concerning different users. Low task complexity has a mean of 8,00 and a standard deviation of 1,31 whereas high task complexity has a mean of 11,87 and a standard deviation of 3,34.

Having a look at the Within-Subjects Effects all values for all variables are highly significant ($p<.001$). Therefore a change of the independent variables has a significant effect on the number of attention shifts.

Pairwise Comparison with Bonferroni Correction of the Anova is significant ($p<.001$) for both independent variables, design as well as task complexity.

6.4.3 Errors

Similar to the previous two user studies, only very few errors occurred during the execution of the tasks. Once again the reason might be that all users spent some time to familiarize themselves with the application beforehand. Figure 6.14 shows the mean and standard deviation for all prototypes and all tasks.

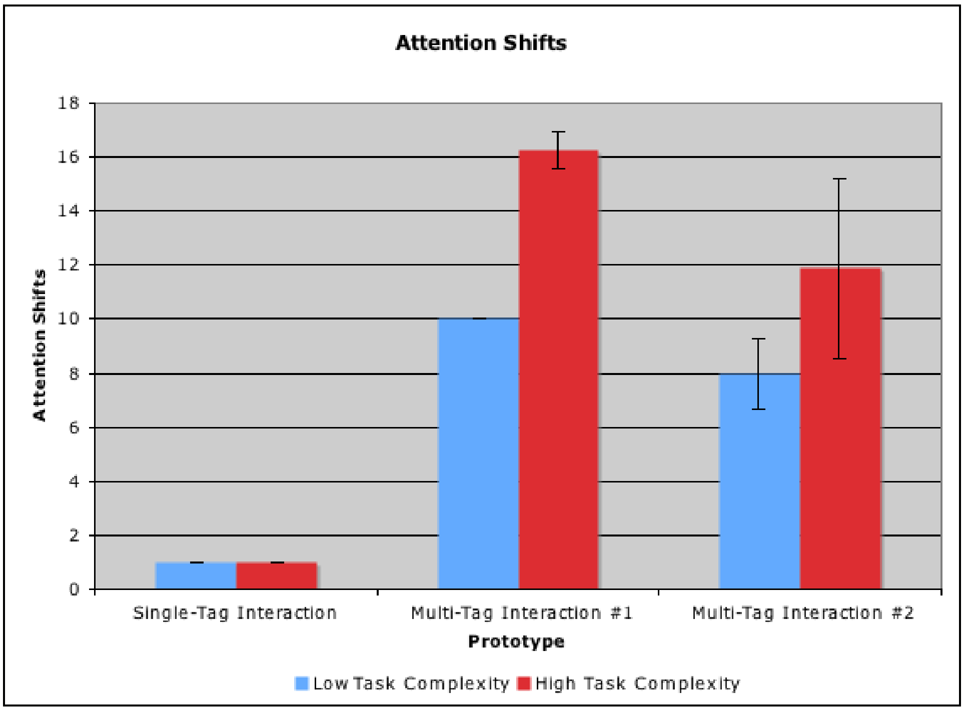

Figure 6.13: The mean and standard deviation of the attention shifts for all three prototypes and all scenarios.

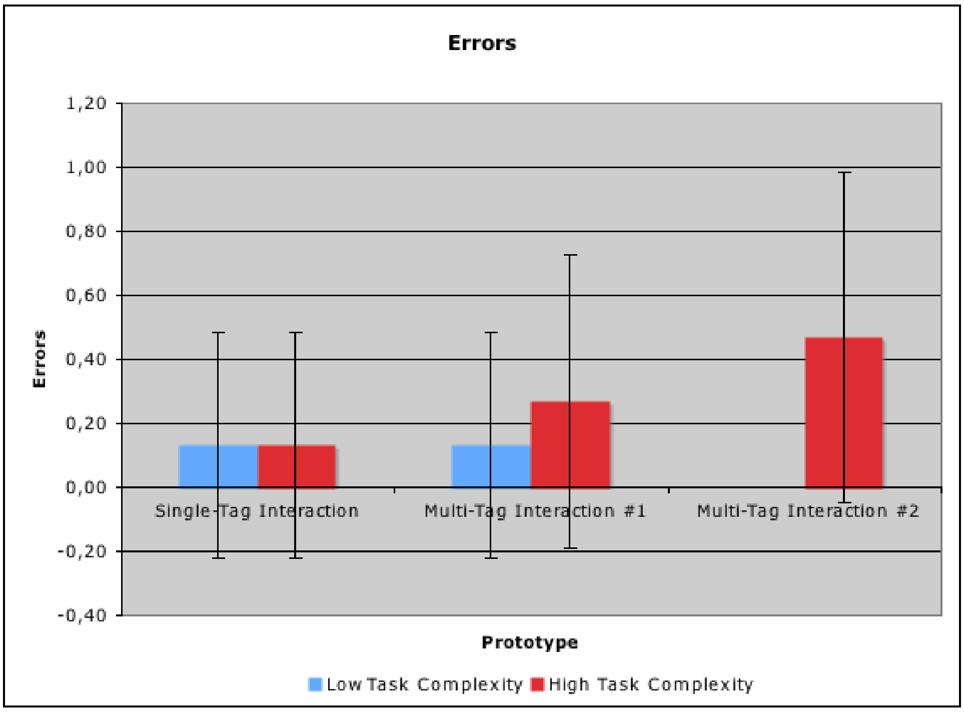

Figure 6.14: The mean and standard deviation of the errors for all three prototypes and all scenarios.

Having a look at the Kolmogorov-Smirnov's Test of Normality all variables that could be taken into account are highly significant (p<.001). Therefore no normal distribution can be detected.

Mauchly's Test of Sphericity shows no significance for design or the combination of design and task complexity. Consequently the condition of sphericity is not met. Task complexity alone cannot be evaluated by Mauchly's Test because this independent variable only has two levels.

Using Single-Tag Interaction all errors that occurred where due to the drop down. About one third of all participants had problems using it at the beginning. They did not know how to get the list of items and tried the arrow down button instead of the soft key in the middle, even though they all had time beforehand to test everything and were told how to use it. For both tasks, low and high complexity the mean is 0,13 and the standard deviation is 0,35.

Problems, while interacting with Multi-Tag Interaction #1, were either caused by the usage of the drop down, too, or by the fact that users had to press "Ok" after each selection and forgot about that. This led to a mean of 0,13 and a standard deviation of 0,35 for low task complexity and a mean of 0,27 and a standard deviation of 0,46 for high task complexity.

Using Multi-Tag Interaction #2 no errors occurred carrying out the task with low complexity (m=0,00; sd=0,00). Except one user, who forgot to touch the start tag, all errors during the task with high complexity were related to the section mediatype, which offered the user the option to select more than one item. Therefore the removal of an already selected item, as requested in the high complexity task, was implemented by touching the item again, which one wants to remove. In contrast to all other fields, where only one item could be selected and removal was implemented by touching the other desired tag. This led to a lot of confusion by the users although they were told about this beforehand (m=0,47; sd=0,52).

The test of Within-Subjects Effects shows significance for the independent variable task complexity. Therefore task complexity had an effect on the number of errors, whereas there is no proven effect concerning the variable design or the combination of design and task complexity.

At last Pairwise Comparison with Bonferroni Correction shows no significance for all combinations of design, but, in unison to the Within-Subjects Effects, a change between low and high task complexity is significant and therefore has an influence on the number of errors.

6.4.4 Execution Time

Similar to the previous two user studies, the execution time has been recorded by the application itself, starting with the launch of the application and ending as soon as the search results are displayed on the mobile device.

Having a look at the Tests of Normality of the Kolmogorov-Smirnov, only one test case, Single-Tag Interaction with low task complexity, shows significance. All other combinations of design and task complexity are therefore normally distributed.

Mauchly's Test of Sphericity is not applicable to the independent variable task complexity because it only has two levels. The independent variable design is significant. Consequently the condition of sphericity is not met and some conditions are more related than others. In contrast the combination of design and task complexity is not significant and therefore the condition of sphericity is met.

Figure 6.15 shows the means and standard deviations for all three prototypes and both task complexities.

In detail Single-Tag Interaction with low task complexity caused an execution time with m=25874,00 and sd=8769,37, whereas high task complexity caused m=37396,00 and sd=8796,40.

Multi-Tag Interaction #1 had m=38701,53 and sd=13616,57 for low task complexity and m=55681,20 and sd=14359,11 for high task complexity. Consequently Multi-Tag Interaction #1 was the slowest prototype.

Executing the tasks using Multi-Tag Interaction #2 led to m=24257,87 and sd=6438,03 for low task complexity and m=41446,87 and sd=10891,74 for high task complexity.

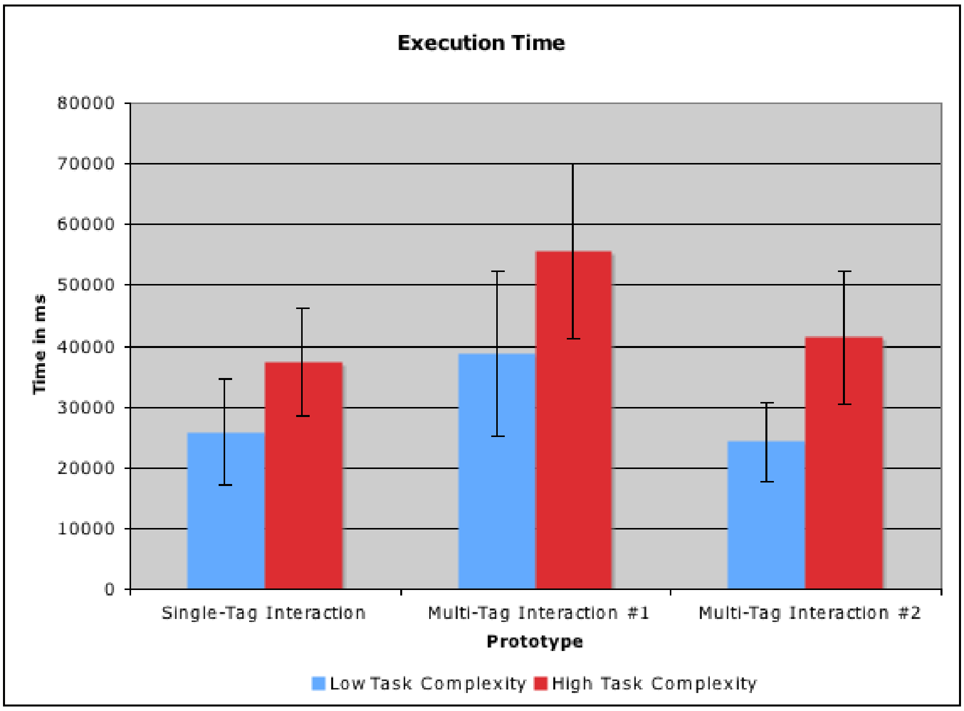

Figure 6.15: The mean and standard deviation of the execution time for all three prototypes and all scenarios.

Having a look at the Test of Within-Subjects Effects of the repeated measure Anova for several independent variables, one can see that both independent variables design and task complexity are significant whereas the combination of both is not significant. Consequently the individual independent variables affected the execution time.

Pairwise Comparison with Bonferroni Correction shows no significance for the combination of Single-Tag Interaction and Multi-Tag Interaction #2. All other design combinations are significant and therefore the interchange of those designs caused an effect. Pairwise Comparison for the independent variable task complexity shows significance ($p<.000$), hence the different levels of the independent variable task complexity have an impact on the execution time.

Keystroke-Level Model

As already known from the previous two user studies the Keystroke-Level Model [17] has been applied to all scenarios and all prototypes.

Figure 6.16 depicts the results for Single-Tag Interaction. As one can see calculated times and measured times are very close together.

In contrast to Single-Tag Interaction figure 6.17 shows that the results of calculated times and measured times for Multi-Tag Interaction #1 are rather far apart. The same assumptions as in 5.4.4 apply here, too. Attention shifts often have been very short, as the video analysis shows. Therefore having to add a "mental act" (1,35s) before every macro attention shift (0,36s) might be part of the reason. Furthermore, due to the very linear layout of the poster, the user probably is faster in pointing than assumed with 1 second. Furthermore the Keystroke-Level Model was based on the older and therefore slower Nokia 3220, which also might have led to a shorter response time in this study. Anyway all these are only assumptions and to ensure those there would be a more detailed evaluation at order.

Figure 6.18 shows the measured and calculated times as well as the calculated times with

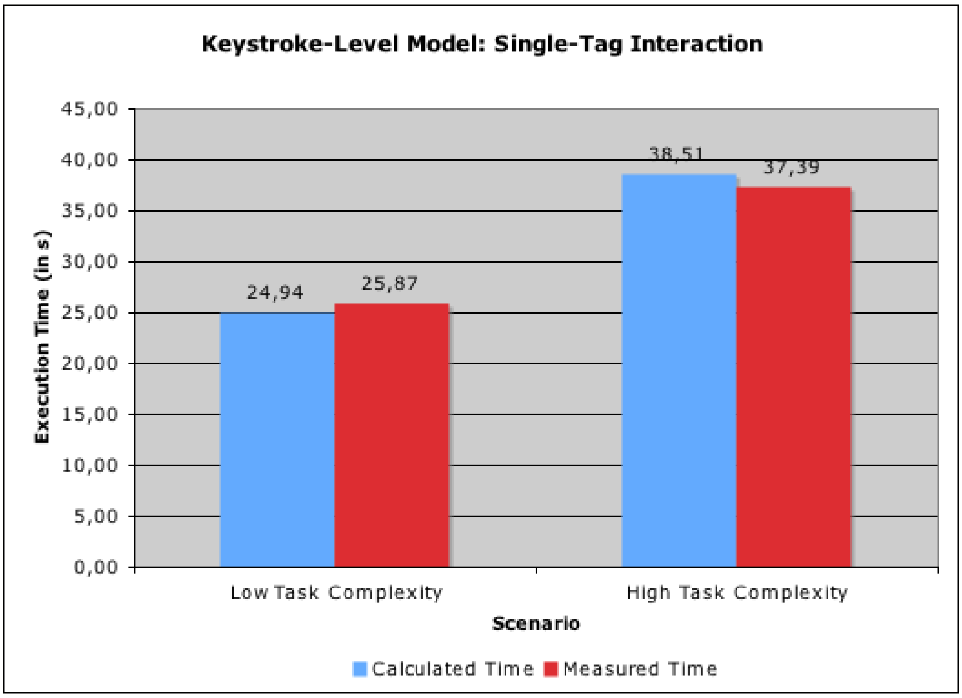

Figure 6.16: The calculated and measured times for Single-Tag Interaction.

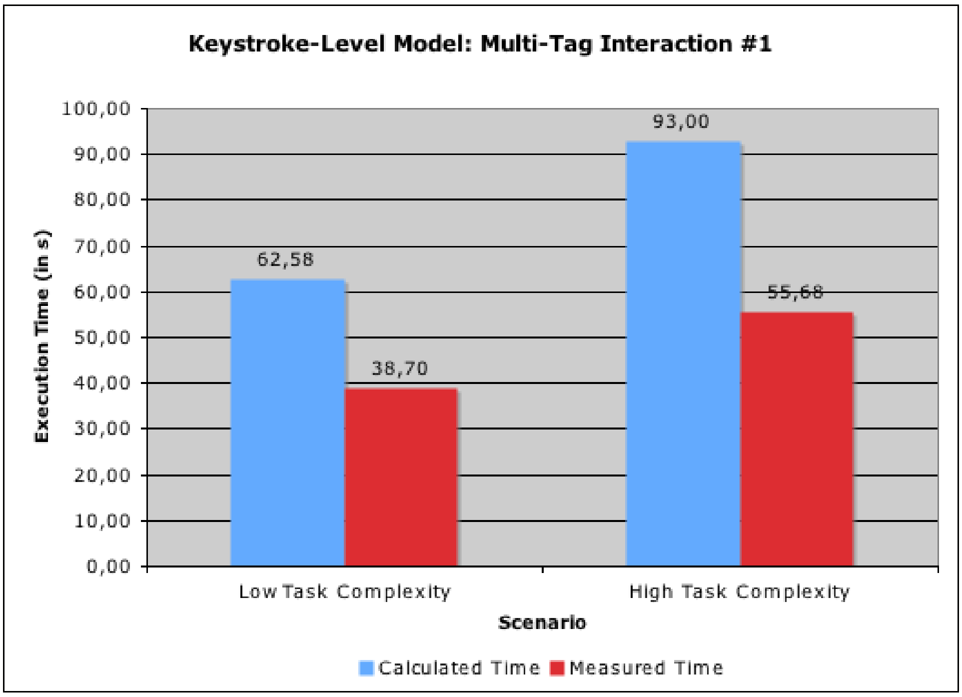

Figure 6.17: The calculated and measured times for Multi-Tag Interaction #1.

measured attention shifts for Multi-Tag Interaction #2. Similar to the first user study the users, using Multi-Tag Interaction #2, carried out less attention shifts than assumed. Anyway, even after the reduction of the attention shifts the model leads to a too long execution time. The same reasons as explained for Multi-Tag Interaction #1 can be given here, too. Generally as one can see looking at all three prototypes one can say that the time difference gets bigger as the number of tags is increased. Therefore, although everything else are only assumptions, one can be pretty sure that the failure of the Keystroke-Level Model is based on the NFC interaction.

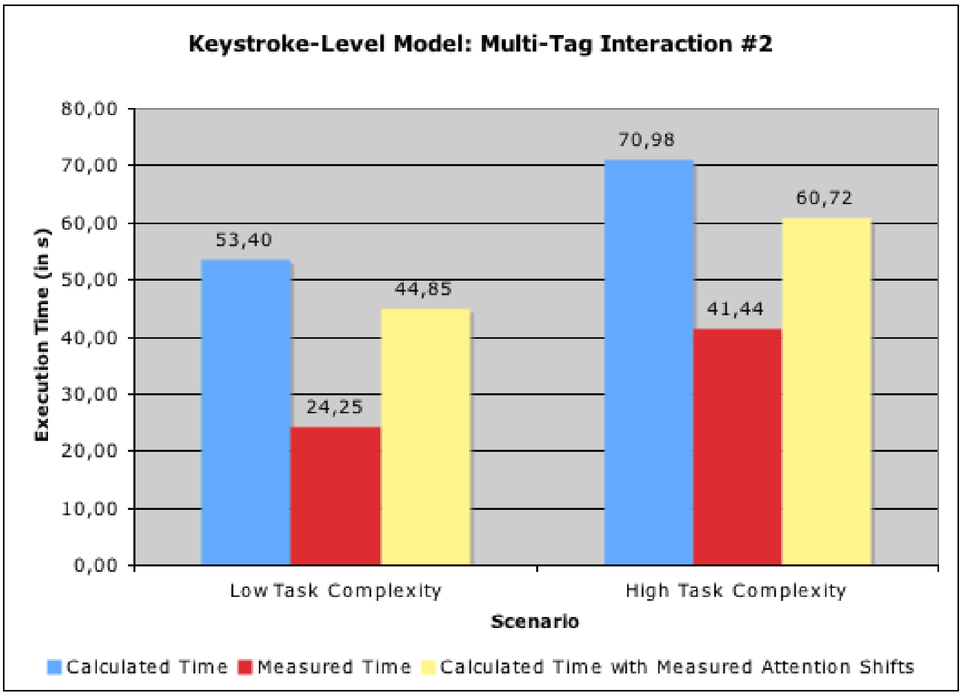

Figure 6.18: The calculated times, measured times and calculated times with measured attention shifts for Multi-Tag Interaction #2.

6.4.5 Verifying the Hypotheses

Having evaluated the dependent variables the beforehand established hypotheses can be rechecked.

The first hypotheses expected Single-Tag Interaction to be the slowest prototype. But in fact Multi-Tag Interaction #1 was the slowest prototype during this user study.

Consequently concerning execution time the second hypotheses has to be confuted. Multi-Tag Interaction #2 turned out to be the fastest, followed by Single-Tag Interaction. Multi-Tag Interaction #1 is considerable slower than the other two. Considering attention shifts the order is as follows: Multi-Tag Interaction #1 with the most attention shifts followed by Multi-Tag Interaction #2 and Single-Tag Interaction. Errors occurred very few but some with every prototype. The only conspicuousness is high task complexity using Multi-Tag Interaction #2, which was due to problems changing the mediatype.

6.4.6 User Feedback

Qualitative data has been collected in the third user study, too. The same modified IBM "Computer System Usability Questionnaire" (see appendix) as in the second user study was used after each prototype. Furthermore in the end a comparing questionnaire was presented.

Modified IBM "Computer System Usability Questionnaire"

The modified IBM "Computer System Usability Questionnaire", as already stated, consisted of eleven questions, all rated with a Likert scale from -3 to +3, and some free comment fields.

Figure 6.19 shows the results for all eleven questions and all three prototypes.

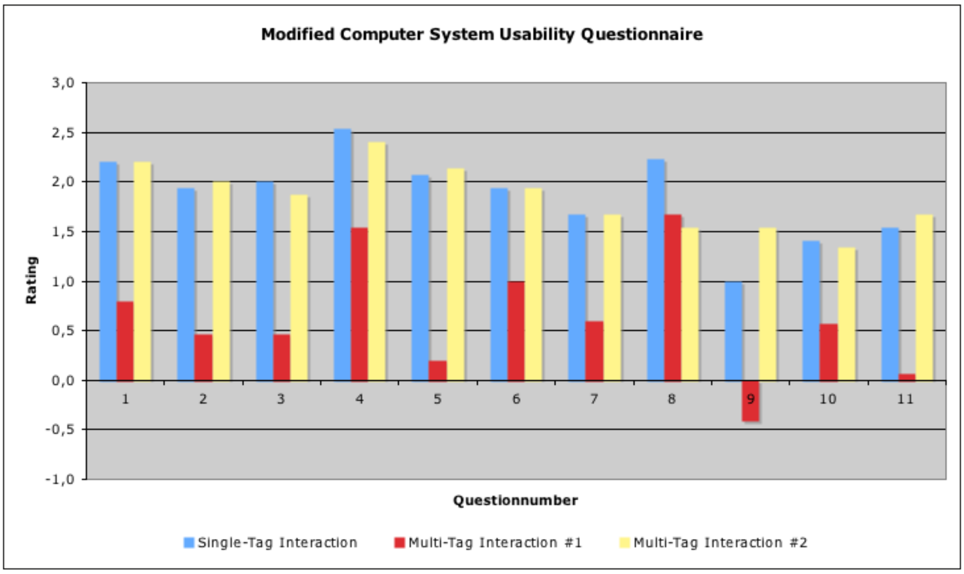

Figure 6.19: The results of the modified IBM "Computer System Usability Questionnaire".

Being asked how simple the usage of the design is, Single-Tag Interaction and Multi-Tag Interaction #2 both got a rating of 2,2 whereas Multi-Tag Interaction #1 only got 0,8.

Completing the work quickly was possible using Multi-Tag Interaction #2 (2,0) and Single-Tag Interaction (1,9) but Multi-Tag Interaction #1 was not really successful in this category (0,5).

Being asked about the efficiency to complete a task, Single-Tag Interaction scored 2,0 closely followed by Multi-Tag Interaction #2 (1,9). Multi-Tag Interaction #1 does not support efficiency very good (0,5).

Learnability was quite good for all prototypes. Single-Tag Interaction was rated with 2,5. Multi-Tag Interaction #2 with 2,4 and Multi-Tag Interaction #1 with at least 1,5.

Becoming productive quickly was possible with Single-Tag Interaction and Multi-Tag Interaction #2 (both 2,1). Multi-Tag Interaction #1 only was rated with only 0,2.

Recovering from mistakes was easy using Single-Tag Interaction and Multi-Tag Interaction #2 (both 1,9). Using Multi-Tag Interaction #1, recovering from a problem was mediocre (1,0).

The organisation of the information on the mobile interface was rated with 1,7 for both Single-Tag Interaction and Multi-Tag Interaction #2. Multi-Tag Interaction #1 was rated with 0,6.

The organisation of information on the physical interface was pretty clear in every prototype. Actually this is the only category where Multi-Tag Interaction #1 did not get the lowest rating. Single-Tag Interaction was rated with 2,2, Multi-Tag Interaction #1 with 1,7 and Multi-Tag Interaction #2 with 1,5.

Being asked about how much they like using the interface, all three prototypes did not do very well. Multi-Tag Interaction #2 got the highest rating with 1,5 followed by Single-Tag Interaction with 1,0. Multi-Tag Interaction #1 was actually quite detested (-0,4).

Asking whether the design had all functions and capabilities one expected, Single-Tag Interaction scored 1,4, closely followed by Multi-Tag Interaction #2 with 1,3. Multi-Tag Interaction #1 only scored 0,6

The overall satisfaction was mediocre all in all. Multi-Tag Interaction #2 was rated with 1,7, while Single-Tag Interaction was rated with 1,5. Very unsatisfying was the usage of Multi-Tag Interaction #1 with only 0,1.

Besides the Likert scale based ratings, users stated their opinion in free comments for negative as well as positive feedback on each prototype.

Generally speaking the users were indifferent about the haptic feedback. Some really liked it, while others felt disturbed by it or even considered it to be a hint about a mistake. A possible solution would be to offer haptic feedback as an option, which can be turned on or off. Some users missed T9 (text on 9 keys) when having to type into the text field. Other general suggestions have been that one could show the availability of a medium in the search results. Furthermore some users had problems using NFC. One user thought he is supposed to keep the mobile device close to the tag the whole time. Another one felt not comfortable having to come so close to the poster with his mobile device.

Using Single-Tag Interaction, users remarked that it could become very cumbersome if the form one is supposed to fill out is longer and more scrolling is necessary. Furthermore one has to deal with the keypad and small display of the mobile device quite a lot. Moreover users stated that the mobile interface was not always clear to them e.g. the "blank line" is not necessarily interpreted as text field. Besides many subjects did not like the start-tag in this prototype because it does not add a real benefit to the overall application. Positive remarks about Single-Tag Interaction have been that all in all the application is similar to the one they knew from the internet and therefore one is already familiar with it and sees on the first glance all available functions. This led to a quick and easy handling. Furthermore, due to the fact that one does not need any tags, the application is always and everywhere available.

About the usage of Multi-Tag Interaction #1 the following feedback has been given. The strongest point of criticism was the permanent switching between the mobile interface and the physical interface. Furthermore after each input parameter the user had to confirm the selection with the right soft key labeled "Ok", which was annoying to the users. Some users were confused about the way they are able change information that they have already input. Submitting the search request with the help of a tag did not appear to be intuitive. Further suggestions concerning the mobile interface have been to combine search parameter and text field on one screen. Additionally users expected radio buttons instead of the drop down when selecting the search parameter. Anyway, users still considered the design to be fast and comprehensible. Furthermore the linear arrangement of the tags on the poster is supposed to be a clear arrangement.

Using Multi-Tag Interaction #2, the handling of the application was not always intuitive. Problems have been the confirmation of the text field with "Ok" and especially with correcting previously made input. Generally the difference of radio buttons and checkboxes was not clear to the users although they were graphically represented by circles and squares. The suggestion was to work with colors because this would be more obvious. Further problems with correction have been that one user thought he needs to start at the beginning with the start-tag to carry out correction. Others found it confusing that they could change the search parameter without changing the text field. Moreover one user would have preferred to input text with the help of a poster e.g. with 26 tags for the letters. Generally a manual was missing one user complained. Nonetheless the workflow was considered to be very fast. The fact that there are less attention shifts necessary than with Multi-Tag Interaction #1 was positively noted, too.

Closing Questionnaire

Similar to the previous two user studies, the users were asked to fill out a closing questionnaire in the end, which asked them for the comparison of the presented prototypes.

Being asked, which prototype they considered to be the best for the given tasks, the users were undecided between Single-Tag Interaction (7 votes) and Multi-Tag Interaction #2 (8 votes). Reasons for Single-Tag Interaction have been that it is similar to the already known online forms, that it is accessible everywhere because one does not need any tags, since the start-tag can be replaced by a normal start of the application with the help of the mobile devices menu. Furthermore using tag-enhanced posters could lead to many users wanting to use them but not all can access the tags at the same time. Moreover there is no necessity for attention shifts. Reasons for choosing Multi-Tag Interaction #2 have been that it appears to be a fast interaction style, all options are available on the first glance without navigating through a menu and one does not have to type in a lot using the keypad. One user simple stated "it's fun". Multi-Tag Interaction #1 was not chosen at all.

The least preferred design is Multi-Tag Interaction #1 (11 votes). Multi-Tag Interaction #2 (2 votes) and Single-Tag Interaction (1 vote) are only disliked by very few people. Reasons for Multi-Tag Interaction #1 not to come off well have been the permanent switching between the mobile and the physical interface, which also caused a longer execution time and a more cumbersome error correction. Furthermore the confirmation with "Ok" appeared to be annoying.

Asking the users, which interaction style - mobile interface only, tag-enhanced poster only or a combination of both - they generally preferred for this task, nine participants stated tag-enhanced posters as their favorite. Five preferred interaction with the mobile interface only and one person liked the combination of both. Reasons for the tag-enhanced posters have been that they offer a good overview over all options. Furthermore using only or at least mainly the poster, the number of attention shifts is greatly reduced. Generally the users have the impression of being faster using the tags and they liked that the number of key presses is greatly reduced. And some users stated that it is just fun using the technology. Arguments for the exclusive use of the mobile interface have been that there is always at least some input, which has to be done using the mobile interface and therefore, to reduce attention shifts one can execute everything directly using the mobile interface. Another big advantage of the solely usage of the mobile interface is that the application can be used everywhere and is not tied to tags. At last for some users, this interaction style appeared to be the fastest.

The tag-enhanced posters used circles and squares to indicate the difference between radio buttons and checkboxes. Users have been asked whether they recognized that. From all fifteen users only one person noticed that. Although some admitted that it is quite understandable once knowing but they just did not see it while using the application. Suggestions for improvements, which have been given are that other tags, which do not represent radio buttons should not be circled as well. Further improvements can be made by using colors to distinguish the different widgets. Additionally one can use clearer symbols e.g. not only circles and squares but graphically show radio buttons and checkboxes.

In the following, the users have been asked about distinct parts of the whole application and whether they want to carry them out by using the mobile interface, the physical interface or both. Starting the application was favored by eight participants with the help of the tag-enhanced poster. Five participants did not care one way or the other and two would prefer starting with the help of the mobile device only. Navigation, e.g. switching between the different search options, also should be carried out using the poster according to eight users, four would prefer interaction with the mobile interface and three liked both. Being asked where to select the different options of one category six people voted for poster as well as for mobile interface whereas three people liked both possibilites. Submitting the search request can be done using both, the poster as well as the mobile interface according to seven participants. Five participants voted for the poster and only three for the mobile application, which is surprising because in the two previous user studies users preferred to carry out the last step using the keypad because it gives them a feeling of being in control. Maybe the reason is that searching for a book does not seem that crucial as other use cases. Summaries are preferred to be shown on the mobile interface by eight subjects. Five would like to see it on the physical interface and one person does not care one way or the other. Correction of errors should be done using the physical interface according to six users. Further six users do not mind whether to use the physical or the mobile interface whereas three prefer the mobile interface. Help should be given on the tag-enhanced poster according to nine participants. Five would like to get help using the mobile interface and one person likes both ideas.

Generally the interaction between mobile device and tag-enhanced poster was intuitive for the users. Concerning the provision of help there have been given different suggestions. According to one user, depending on the focus of the application, either on the mobile application or on the tag-enhanced poster, the information should be provided. Others had strong feelings for either the mobile interface or the tag-enhanced poster to be the better place for information. One probably can say that it depends on the person, which way is preferred and a possible solution would be to offer both. Other suggestions have been to offer a tutorial tag, which takes the user through the whole application step-by-step.

Problems that user stated have been general problems reading the tags, the permanent attention shifts between poster and mobile interface, the different handling concerning correction of radio buttons and checkboxes and the confirmation with "Ok", which has often been forgotten.

Suggestions for improvements have been to replace the drop down with radio buttons because they are easier to handle, the text field should be labeled and text input should also be possible with the help of the poster. Furthermore some users would prefer audio feedback instead of haptic feedback.

7 Conclusion

This thesis evaluated the design and distribution of physical and mobile interfaces for multi-tag interaction. After evaluating different related work, a categorisation for multi-tag interaction was given. In the following, three of those categories have been evaluated in three different user studies.

Based on these user studies some results can be summarized. In general users are open minded regarding physical mobile interaction based on NFC. They describe it as a fun technology, which they enjoy using. Anyway some important aspects have to be kept in mind when developing such an application.

Evaluating "Navigation" and "Selection" with the help of a menu, which supported ordering different meals for different courses, the following most important results should be kept in mind. It turns out to be not very handy to use physical mobile interaction for navigation only, because this leads to a high number of attention shifts, which is not very enjoyed by the users. Navigation with the help of the mobile interface only does not seem that cumbersome to justify the high amount of attention shifts. In contrast offering selection as physical mobile interaction can be declared as huge success. Execution time decreases when doing so, especially if a lot of items are offered to choose from. Furthermore, even though navigation only does not offer any benefit, the combination of selection and navigation transfered to the physical interface turned out to be the fastes approach, led to the least attention shifts disregarding single-tag interaction and achieved the best ratings concerning qualitative data. Generally users prefer high freedom in the order of the execution of a task. They want to feel in control instead of feeling controlled by the application.

During the second user study, dealing with the category "Combination of Information", one could observe that combining different information, like in this case sights and actions, execution time is best when doing this completely with the help of tags. The usage of combined tags, meaning one tag already contains the combination of a sight and an action, turned out to be the fastest solution. But using a combination of two tags, one for the sight and one for the action, is only slightly slower. In comparison all prototypes that required the user to select at least one item using the mobile interface turned out to be significantly slower. Also qualitative data provided by the subjects emphasized this and their preference of combining information with the help of tags and the physical interface instead of the mobile interface. This is once again based on the higher freedom during the execution of the task and consequently less forced attention shifts.

The third user study, which refined the evaluation of "Navigation" and "Selection" with the help of GUI widgets, pointed out the importance of a clearly designed physical interface. The distinction and consequently different handling of tags representing checkboxes and radio buttons has not been clear to most participants. The problem is that the physical interaction of touching a tag is always the same but the mental model needs to differ. This has to be made really clear to the user by means of the the design of the physical interface. Using circles and squares as done in this user study seems not to be enough. This user study demonstrates that multi-tag interaction is not necessarily the best solution for every use case. Although the prototype, which combined navigation and selection on the physical interface, was enjoyed by the participants, Single-Tag Interaction was also very much liked. This observation was also supported by the evaluation of the quantitative data, which also attested good results to Single-Tag Interaction.

Consequently, having a look at all three user studies and all prototypes, some general results concerning physical mobile interaction and especially multi-tag interaction can be summarized.

A good layout of tags is important. Otherwise single-tag applications - which also work with no tag at all, by starting them with the help of the mobile device's menu - should not be underestimated because they have not been the slowest and worst prototypes during all studies. As stated, using NFC-tags for navigation only is proven to be problematic because a lot of attention shifts are caused by that whilst not adding this much additional features to the application. In general, it seems advisable to either put the main focus on the mobile interface or on the physical interface but avoid permanent switches between those two.

Furthermore it is of upmost importance to make clear how each tag works. Whenever an application uses tags in different contexts it is important to clearly point that out to the user.

Anyway users like to have huge freedom during the usage of an application. They enjoy the feeling of being in control. This is especially important while carrying out more crucial tasks like submitting an order. They prefer using a key press instead of a tag, because they have the impression that a key cannot that easily be pressed accidentally in comparison to touching a tag by accident.

A further general request concerning all applications was not having to explicitly start the applications with the help of a start-tag. Instead, by touching any tag, the mobile device should be able to recognize, which application is supposed to be started. This would reduce the overall interaction of one step and offer a faster access to the actual information, which can be acquired by the application.

Help and information on the usage of NFC is very important and should be easily accesible as well as the possibility to correct already given input.

All in all there is a lot of potential in this kind of interaction, but some further investigation will be needed in various fields. Beside the not yet tested fourth category "Mapping" other research areas can be imagined.

All prototypes shown in this thesis offer either the possibility to process something with the help of a mobile or a physical interface. Offering a prototype, which supports both in one single application would for sure present interesting results concerning the user's decision. Which steps will be carried out using the mobile interface, which will be carried out using the physical interface? Although this of course has been part of the evaluation, not all single interaction steps throughout one use case have been presented in both ways.

Moreover help was mainly provided by the investigator. Only very few and very limited information about the usage was given on the application's interface. Suggestions given by the users range from textual explanations on the physical interface, feedback on the mobile device to tutorial-tags, which can be touched, but none of this has been investigated more closly.

All in all, this thesis gives a preliminary categorisation for multi-tag interaction, some general hints on usability related topics concerning interaction with tags and a more detailed insight concerning the distribution of the interface. But the correctness of this division, and concrete applications following these guidelines, have to establish themselves in the future.

References

[1] BALLAGAS, Rafael ; ROHS, Michael ; SHERIDAN, Jennifer G.: Sweep and point and shoot: phonecam-based interactions for large public displays. In: *CHI '05: CHI '05 extended abstracts on Human factors in computing systems*. New York, NY, USA : ACM, 2005, P. 1200–1203

[2] BELT, Sara ; MÄKELÄ, Kaj ; GREENBLATT, Dan ; HÄKKILÄ, Jonna: Mobile interaction with visual and RFID tags: a field study on user perceptions. In: *CHI '07: Proceedings of the SIGCHI conference on Human factors in computing systems*. New York, NY, USA : ACM, 2007, P. 991–994

[3] BROLL, Gregor ; BENFORD, Steve: Seamful Design for Location-Based Mobile Games. In: *ICEC* Bd. 3711, Springer, 2005 (Lecture Notes in Computer Science), P. 155–166

[4] BROLL, Gregor ; HAARLÄNDER, Markus ; PAOLUCCI, Massimo ; WAGNER, Matthias ; RUKZIO, Enrico ; SCHMIDT, Albrecht: Collect&Drop: A Technique for Multi-Tag Interaction with Real World Objects and Information. In: *AmI '08: Proceedings of the European Conference on Ambient Intelligence*. Berlin, Heidelberg : Springer-Verlag, 2008, P. 175–191

[5] BROLL, Gregor ; SIORPAES, Sven ; RUKZIO, Enrico ; PAOLUCCI, Massimo ; HAMARD, John ; WAGNER, Matthias ; SCHMIDT, Albrecht: Comparing Techniques for Mobile Interaction with Objects from the Real World. In: *3rd International Workshop on Pervasive Mobile Interaction Devices*. Toronto, Ontario, Canada : PERMID, 2007

[6] BROLL, Gregor ; SIORPAES, Sven ; RUKZIO, Enrico ; PAOLUCCI, Massimo ; HAMARD, John ; WAGNER, Matthias ; SCHMIDT, Albrecht: Supporting Mobile Service Usage through Physical Mobile Interaction. In: *PerCom*, IEEE Computer Society, 2007, P. 262–271

[7] BROWNE, Dean ; SIMON, Randy: *J4ME*. `http://code.google.com/p/j4me/`, Last checked: 20-03-2009

[8] CITY-MOBILE: *City-Mobile: Nokia 6131 NFC Specifications*. `http://www.city-mobile.co.uk/buy/nokia-6131-nfc/5945.html`, Last checked: 20-03-2009

[9] FIELD, Andy: *Discovering Statistics Using SPSS*. SAGE Publications, 2000

[10] FIELD, Andy ; HOLE, Graham: *How to Design and Report Experiments*. SAGE Publications, 2003

[11] GEVEN, Arjan ; STRASSL, Peter ; FERRO, Bernhard ; TSCHELIGI, Manfred ; SCHWAB, Harald: Experiencing real-world interaction: results from a NFC user experience field trial. In: *MobileHCI '07: Proceedings of the 9th international conference on Human computer interaction with mobile devices and services*. New York, NY, USA : ACM, 2007, P. 234–237

[12] HÄIKIÖ, Juha ; WALLIN, Arto ; ISOMURSU, Minna ; AILISTO, Heikki ; MATINMIKKO, Tapio ; HUOMO, Tua: Touch-based user interface for elderly users. In: *MobileHCI '07: Proceedings of the 9th international conference on Human computer interaction with mobile devices and services*. New York, NY, USA : ACM, 2007, P. 289–296

[13] HARDY, Robert ; RUKZIO, Enrico: Direct Touch-based Mobile Interaction with Dynamic Displays. In: *CHI08 Workshop: Designing and Evaluating Mobile Phone-Based Interaction with Public Displays*. Florence, Italy, 2008

[14] HARDY, Robert ; RUKZIO, Enrico: Touch & interact: touch-based interaction of mobile phones with displays. In: *MobileHCI '08: Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*. New York, NY, USA : ACM, 2008, P. 245–254

[15] HARDY, Robert ; RUKZIO, Enrico ; WAGNER, Matthias ; PAOLUCCI, Massimo: Touch & Interact: Applied to a Tourist Guide Prototype. In: *Demonstration at NFC Forum Global Competition at 2nd European NFC Developers Summit*. Monaco, 2008

[16] HERTING, Tanja ; BROLL, Gregor: Acceptance and Usability of Physical Mobile Applications. In: *MIRW*, 2008, P. 15–26

[17] HOLLEIS, Paul ; OTTO, Friederike ; HUSSMANN, Heinrich ; SCHMIDT, Albrecht: Keystroke-level model for advanced mobile phone interaction. In: *CHI '07: Proceedings of the SIGCHI conference on Human factors in computing systems*. New York, NY, USA : ACM, 2007, P. 1505–1514

[18] KINDBERG, Tim ; BARTON, John ; MORGAN, Jeff ; BECKER, Gene ; CASWELL, Debbie ; DEBATY, Philippe ; GOPAL, Gita ; FRID, Marcos ; KRISHNAN, Venky ; MORRIS, Howard ; SCHETTINO, John ; SERRA, Bill ; SPASOJEVIC, Mirjana: People, places, things: web presence for the real world. In: *Mob. Netw. Appl.* 7 (2002), Nr. 5, P. 365–376

[19] MEIJER, Peter B.L.: *The vOICe MIDlet for Mobile Camera Phones*. http://www.seeingwithsound.com/midlet.htm, Last checked: 10-03-2009

[20] NOKIA: *Nokia 6131 NFC SDK: Programmer's Guide*. http://sw.nokia.com/id/1f75c9a5-3aeb-42e9-890d-f06e3b2e94d9/Nokia_UI_API_Programmers_Guide_v1_1_en.pdf, Last checked: 23-06-2009

[21] NOKIA: *Nokia 6131 NFC SDK: Users's Guide*. http://sw.nokia.com/id/77d9e449-6368-4fde-8453-189ab771928a/Nokia_6131_NFC_SDK_Users_Guide_v1_1_en.pdf, Last checked: 23-06-2009

[22] O'NEILL, Eamonn ; THOMPSON, Peter ; GARZONIS, Stavros ; WARR, Andrew: Reach Out and Touch: Using NFC and 2D Barcodes for Service Discovery and Interaction with Mobile Devices. In: *Pervasive* Bd. 4480, Springer, 2007 (Lecture Notes in Computer Science), P. 19–36

[23] OPENSTREETMAP: *OpenStreetMap - Die freie Wiki-Weltkarte*. http://www.openstreetmap.de, Last checked: 26.04.2009

[24] PERLMAN, Gary: *Web-Based User Interface Evaluation with Questionaires*. http://hcibib.org/perlman/question.html, Last checked: 27-01-2009

[25] REILLY, Derek ; WELSMAN-DINELLE, Michael ; BATE, Colin ; INKPEN, Kori: Just point and click?: using handhelds to interact with paper maps. In: *MobileHCI '05: Proceedings of the 7th international conference on Human computer interaction with mobile devices & services*. New York, NY, USA : ACM, 2005, P. 239–242

[26] ROHS, Michael: Visual Code Widgets for Marker-Based Interaction. In: *ICDCSW '05: Proceedings of the Fifth International Workshop on Smart Appliances and Wearable Computing*. Washington, DC, USA : IEEE Computer Society, 2005, P. 506–513

[27] RUKZIO, Enrico ; BROLL, Gregor ; LEICHTENSTERN, Karin ; SCHMIDT, Albrecht: Mobile Interaction with the Real World: An Evaluation and Comparison of Physical Mobile Interaction Techniques. In: *AmI* Bd. 4794, Springer, 2007 (Lecture Notes in Computer Science), P. 1–18

[28] RUKZIO, Enrico ; LEICHTENSTERN, Karin ; CALLAGHAN, Victor ; HOLLEIS, Paul ; SCHMIDT, Albrecht ; CHIN, Jeannette Shiaw-Yuan: An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning. In: *Ubicomp* Bd. 4206, Springer, 2006 (Lecture Notes in Computer Science), P. 87–104

[29] SÁNCHEZ, Iván ; CORTÉS, Marta ; RIEKKI, Jukka: Controlling multimedia players using NFC enabled mobile phones. In: *MUM '07: Proceedings of the 6th international conference on Mobile and ubiquitous multimedia*. New York, NY, USA : ACM, 2007, P. 118–124

[30] SÁNCHEZ, Iván ; RIEKKI, Jukka ; PYYKKÖNEN, Mikko: Touch & Control: Interacting with Services by Touching RFID Tags. In: *IWRT*, INSTICC PRESS, 2008, P. 53–62

[31] SCHWIEREN, Joachim ; VOSSEN, Gottfried: Implementing Physical Hyperlinks for Mobile Applications Using RFID Tags. In: *IDEAS '07: Proceedings of the 11th International Database Engineering and Applications Symposium*. Washington, DC, USA : IEEE Computer Society, 2007, P. 154–162

[32] SMARTTOUCH: *Case: Restaurant Pannu*. `http://ttuki.vtt.fi/smarttouch/www/?info=case-pannu`, Last checked: 30.05.2009

[33] THE ECLIPSE FOUNDATION: *Eclipse*. `http://www.eclipse.org`, Last checked: 20-03-2009

[34] VÄLKKYNEN, Pasi: Hovering: Visualising RFID Hyperlinks in a Mobile Phone. In: *Proceedings of Mobile Interaction with the Real World*. Espoo, Finland, 2006, P. 27–29

Contents of enclosed CD

1. 1. User Study
    - Application
    - Evaluation
    - Poster
    - SPSS
2. 2. User Study
    - Application
    - Evaluation
    - Poster
    - SPSS
3. 3. User Study
    - Application
    - Evaluation
    - Poster
    - SPSS
4. Related Work
    - Paper
    - Websites
5. Speeches
6. Thesis
    - Diplomarbeit.pdf
    - Latex

Appendix

1. First User Study: Navigation and Selection
   - Demographic Questionnaire (also applicable for the 2. and 3. user study)
   - IBM Questionnaire
   - Closing Questionnaire
   - SPSS Output (only relevant tables)
2. Second User Study: Action and Objects
   - Modified IBM Questionnaire (also applicable for 3. user study)
   - Closing Questionnaire
   - SPSS Output (only relevant tables)
3. Third User Study: GUI Widgets
   - Closing Questionnaire
   - SPSS Output (only relevant tables)

First User Study: Navigation and Selection

- Demographic Questionnaire (also applicable for the 2. and 3. userstudy)
- IBM Questionnaire
- Closing Questionnaire
- SPSS Output (only relevant tables)

Demographie-Fragebogen

Teilnehmer: ________

1. **Demographie**

Geschlecht: männlich ◻ weiblich ◻

Alter: ______

Studienrichtung/Beruf: _________________________________

2. **Technisches Vorwissen**

Besitzen Sie selbst ein mobiles Gerät (Handy, PDA,...)?

ja ◻ nein ◻

Wenn ja, seit wie vielen Jahren? ________

Wie würden Sie selbst Ihre Erfahrung mit mobilen Geräten einschätzen?

sehr wenig erfahren ◻ ◻ ◻ ◻ ◻ sehr erfahren

Wie würden Sie selbst Ihr allgemeines technisches Verständnis einschätzen?

sehr schlecht ◻ ◻ ◻ ◻ ◻ sehr gut

Haben Sie den Begriff RFID oder NFC schon mal gehört?

ja ◻ nein ◻

Haben Sie bereits an einer Nutzerstudie zum Thema RFID/NFC teilgenommen?

ja ◻ nein ◻

Questionnaire System Evaluation

Based on: Lewis, J. R. (1995) *IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use*. **International Journal of Human-Computer Interaction**, 7:1, 57-78. Abstract | About question.cgi

Please rate the usability of question.cgi.

- Try to respond to all the items.
- For items that are not applicable, use: **N/A**
- Make sure these fields are filled in: **Design: Email to:**
- Add a comment about an item by clicking on its icon, or add comment fields for all items by clicking on **Comment All**.
- To mail in your results, click on: **Mail Data**

Design: question.cgi **Email to:**

Optionally provide comments and your email address in the box.

Mail Data RETURN TO REFERRING PAGE

		-3	-2	-1	0	1	2	3		N/A
1. Overall, I am satisfied with how easy it is to use this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
2. It was simple to use this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
3. I can effectively complete my work using this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
4. I am able to complete my work quickly using this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
5. I am able to efficiently complete my work using this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
6. I feel comfortable using this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
7. It was easy to learn to use this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
8. I believe I became productive quickly using this design Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○
9. The design gives error messages that clearly tell me how to fix problems Comments:	DISAGREE	○	○	○	○	○	○	○	AGREE	○

10. Whenever I make a mistake using the design, I recover easily and quickly	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
11. The information (such as online help, on-screen messages, and other documentation) provided with this design is clear	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
12. It is easy to find the information I needed	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
13. The information provided for the design is easy to understand	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
14. The information is effective in helping me complete the tasks and scenarios	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
15. The organization of information on the design screens is clear	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
16. The interface of this design is pleasant	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
17. I like using the interface of this design	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
18. This design has all the functions and capabilities I expect it to have	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
19. Overall, I am satisfied with this design	DISAGREE	○	○	○	○	○	○	○	AGREE	○
Comments:										
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**		**N/A**

List the most **negative** aspect(s):

1.
2.
3.

List the most **positive** aspect(s):

1.
2.
3.

Abschluss-Fragebogen

Teilnehmer: ________

1. **Welches Design war für die Durchführung der Aufgabe insgesamt am besten geeignet?**
   - o Single-Tag Interaction
   - o Multi-Tag Interaction 1 (Kategorien und Aktionen auf dem Poster)
   - o Multi-Tag Interaction 2 (Optionen auf dem Poster)
   - o Multi-Tag Interaction 3 (komplette Interaktion über das Poster)

   Warum? Welche Vorteile hat dieses Design?

2. **Welches Design war für die Durchführung der Aufgabe insgesamt am wenigsten geeignet?**
   - o Single-Tag Interaction
   - o Multi-Tag Interaction 1 (Kategorien und Aktionen auf dem Poster)
   - o Multi-Tag Interaction 2 (Optionen auf dem Poster)
   - o Multi-Tag Interaction 3 (komplette Interaktion über das Poster)

   Warum? Welche Nachteile hat dieses Design?

3. **Welche Art der Interaktion bevorzugen Sie für die Durchführung der Aufgabe?**
   - o Auf dem Handy (Interaktion mit regulären Handy-Interfaces)
   - o Auf dem Poster (Interaktion durch Berühren von Tags)
   - o Auf beiden (z.B. Berühren eines Tags auf dem Poster öffnet Liste auf Handy)

Warum? Welche Vorteile hat dieses Design?

4. **Welche Art der Interaktion (auf dem Handy, auf dem Poster oder auf beidem) ist für folgende Teile der Anwendung am besten geeignet?**
    - Starten der Anwendung =>
    - Navigation (Wechsel zwischen den einzelnen Kategorien) =>
    - Auswahl einzelner Optionen =>
    - Ausführen von Aktionen (z.B. submit) =>
    - Gesamtübersicht, Zusammenfassung =>
    - Korrektur von Fehlern =>
    - Hinweise und Hilfe zur Bedienung des Systems =>

5. **Wie möchten Sie bei der Durchführung der Aufgabe geführt werden?**
    - o Vom Handy (legt jeweils nächsten Schritt der Interaktion fest)
    - o Vom Poster (visuelle Hinweise zur Interaktion)
    - o Keine Führung, freie Interaktion mit dem Poster

6. **Bei welchem Design traten Schwierigkeiten auf? Welche?**

7. **Verbesserungsvorschläge oder Kommentare zu den einzelnen Designs?**

Attention Shifts

Kolmogorov-Smirnov

Tests auf Normalverteilung[b,c,d,e,f,g,h,i]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistik	df	Signifikanz	Statistik	df	Signifikanz
P3_TaskL_InterfaceL	.318	16	.000	.707	16	.000
P3_TaskL_InterfaceH	.285	16	.001	.713	16	.000
P3_TaskH_InterfaceL	.287	16	.001	.780	16	.001
P3_TaskH_InterfaceH	.262	16	.004	.865	16	.023
P4_TaskL_InterfaceL	.337	16	.000	.765	16	.001
P4_TaskL_InterfaceH	.316	16	.000	.831	16	.007
P4_TaskH_InterfaceL	.248	16	.010	.894	16	.066
P4_TaskH_InterfaceH	.322	16	.000	.758	16	.001

a. Signifikanzkorrektur nach Lilliefors

b. P1_TaskL_InterfaceL ist konstant und wurde weggelassen.

c. P1_TaksL_InterfaceH ist konstant und wurde weggelassen.

d. P1_TaskH_InterfaceL ist konstant und wurde weggelassen.

e. P1_TaskH_InterfaceH ist konstant und wurde weggelassen.

f. P2_TaskL_InterfaceL ist konstant und wurde weggelassen.

g. P2_TaskL_InterfaceH ist konstant und wurde weggelassen.

h. P2_TaskH_InterfaceL ist konstant und wurde weggelassen.

i. P2_TaskH_InterfaceH ist konstant und wurde weggelassen.

ANOVA

Mauchly-Test auf Sphärizität[b]

Maß:MASS_1

Innersubjekteffekt	Mauchly-W	Approximiertes Chi-Quadrat	df	Signifikanz	Epsilon[a] Greenhouse-Geisser
Prototype	.000	.	5	.	.654
Taskcomplexity	1.000	.000	0	.	1.000
Interfacecomplexity	1.000	.000	0	.	1.000
Prototype * …	.000	.	5	.	.578
Prototype * …	.000	.	5	.	.433
Taskcomplexity * …	1.000	.000	0	.	1.000
Prototype * Taskcomplexity * …	.000	.	5	.	.621

Prüft die Nullhypothese, daß sich die Fehlerkovarianz-Matrix der orthonormalisierten transformierten abhängigen Variablen proportional zur Einheitsmatrix verhält.

a. Kann zum Korrigieren der Freiheitsgrade für die gemittelten Signifikanztests verwendet werden. In der Tabelle mit den Tests der Effekte innerhalb der Subjekte werden korrigierte Tests angezeigt.

b. Design: Konstanter Term
Innersubjektdesign: Prototype + Taskcomplexity + Interfacecomplexity + Prototype * Taskcomplexity + Prototype * Interfacecomplexity + Taskcomplexity * Interfacecomplexity + Prototype * Taskcomplexity * Interfacecomplexity

Mauchly-Test auf Sphärizität[b]

Maß:MASS_1

Innersubjekteffekt	Epsilon[a] Huynh-Feldt	Untergrenze
Prototype	.752	.333
Taskcomplexity	1.000	1.000
Interfacecomplexity	1.000	1.000
Prototype * …	.647	.333
Prototype * …	.458	.333
Taskcomplexity * …	1.000	1.000
Prototype * Taskcomplexity * …	.705	.333

Prüft die Nullhypothese, daß sich die Fehlerkovarianz-Matrix der orthonormalisierten transformierten abhängigen Variablen proportional zur Einheitsmatrix verhält.

a. Kann zum Korrigieren der Freiheitsgrade für die gemittelten Signifikanztests verwendet werden. In der Tabelle mit den Tests der Effekte innerhalb der Subjekte werden korrigierte Tests angezeigt.

b. Design: Konstanter Term
Innersubjektdesign: Prototype + Taskcomplexity + Interfacecomplexity + Prototype * Taskcomplexity + Prototype * Interfacecomplexity + Taskcomplexity * Interfacecomplexity + Prototype * Taskcomplexity * Interfacecomplexity

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Prototype	Sphärizität angenommen	3921.672	3	1307.224
	Greenhouse-Geisser	3921.672	1.963	1997.341
	Huynh-Feldt	3921.672	2.256	1738.053
	Untergrenze	3921.672	1.000	3921.672
Fehler(Prototype)	Sphärizität angenommen	512.578	45	11.391
	Greenhouse-Geisser	512.578	29.452	17.404
	Huynh-Feldt	512.578	33.845	15.145
	Untergrenze	512.578	15.000	34.172
Taskcomplexity	Sphärizität angenommen	380.250	1	380.250
	Greenhouse-Geisser	380.250	1.000	380.250
	Huynh-Feldt	380.250	1.000	380.250
	Untergrenze	380.250	1.000	380.250
Fehler(Taskcomplexity)	Sphärizität angenommen	23.000	15	1.533
	Greenhouse-Geisser	23.000	15.000	1.533
	Huynh-Feldt	23.000	15.000	1.533
	Untergrenze	23.000	15.000	1.533
Interfacecomplexity	Sphärizität angenommen	2.250	1	2.250
	Greenhouse-Geisser	2.250	1.000	2.250
	Huynh-Feldt	2.250	1.000	2.250
	Untergrenze	2.250	1.000	2.250
Fehler (Interfacecomplexity)	Sphärizität angenommen	26.750	15	1.783
	Greenhouse-Geisser	26.750	15.000	1.783
	Huynh-Feldt	26.750	15.000	1.783
	Untergrenze	26.750	15.000	1.783
Prototype * Taskcomplexity	Sphärizität angenommen	172.250	3	57.417
	Greenhouse-Geisser	172.250	1.734	99.352
	Huynh-Feldt	172.250	1.940	88.777
	Untergrenze	172.250	1.000	172.250
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen	72.000	45	1.600
	Greenhouse-Geisser	72.000	26.006	2.769
	Huynh-Feldt	72.000	29.104	2.474
	Untergrenze	72.000	15.000	4.800
Prototype * Interfacecomplexity	Sphärizität angenommen	3.375	3	1.125
	Greenhouse-Geisser	3.375	1.300	2.595
	Huynh-Feldt	3.375	1.373	2.459
	Untergrenze	3.375	1.000	3.375

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Prototype	Sphärizität angenommen	114.763	.000
	Greenhouse-Geisser	114.763	.000
	Huynh-Feldt	114.763	.000
	Untergrenze	114.763	.000
Fehler(Prototype)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity	Sphärizität angenommen	247.989	.000
	Greenhouse-Geisser	247.989	.000
	Huynh-Feldt	247.989	.000
	Untergrenze	247.989	.000
Fehler(Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Interfacecomplexity	Sphärizität angenommen	1.262	.279
	Greenhouse-Geisser	1.262	.279
	Huynh-Feldt	1.262	.279
	Untergrenze	1.262	.279
Fehler (Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity	Sphärizität angenommen	35.885	.000
	Greenhouse-Geisser	35.885	.000
	Huynh-Feldt	35.885	.000
	Untergrenze	35.885	.000
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Interfacecomplexity	Sphärizität angenommen	.482	.697
	Greenhouse-Geisser	.482	.545
	Huynh-Feldt	.482	.554
	Untergrenze	.482	.498

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen	105.125	45	2.336
	Greenhouse-Geisser	105.125	19.506	5.389
	Huynh-Feldt	105.125	20.591	5.105
	Untergrenze	105.125	15.000	7.008
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.016	1	.016
	Greenhouse-Geisser	.016	1.000	.016
	Huynh-Feldt	.016	1.000	.016
	Untergrenze	.016	1.000	.016
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	27.484	15	1.832
	Greenhouse-Geisser	27.484	15.000	1.832
	Huynh-Feldt	27.484	15.000	1.832
	Untergrenze	27.484	15.000	1.832
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.797	3	.266
	Greenhouse-Geisser	.797	1.862	.428
	Huynh-Feldt	.797	2.115	.377
	Untergrenze	.797	1.000	.797
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	43.203	45	.960
	Greenhouse-Geisser	43.203	27.924	1.547
	Huynh-Feldt	43.203	31.723	1.362
	Untergrenze	43.203	15.000	2.880

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.009	.928
	Greenhouse-Geisser	.009	.928
	Huynh-Feldt	.009	.928
	Untergrenze	.009	.928
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.277	.842
	Greenhouse-Geisser	.277	.745
	Huynh-Feldt	.277	.772
	Untergrenze	.277	.607
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-11.000	.000	.	-11.000	-11.000

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Bonferroni.

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	3	-5.750*	.609	.000	-7.598	-3.902
	4	-4.594*	.629	.000	-6.503	-2.685
2	1	11.000	.000	.	11.000	11.000
	3	5.250*	.609	.000	3.402	7.098
	4	6.406*	.629	.000	4.497	8.315
3	1	5.750*	.609	.000	3.902	7.598
	2	-5.250*	.609	.000	-7.098	-3.402
	4	1.156	.778	.946	-1.205	3.517
4	1	4.594*	.629	.000	2.685	6.503
	2	-6.406*	.629	.000	-8.315	-4.497
	3	-1.156	.778	.946	-3.517	1.205

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Bonferroni.

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Task complexity	(J) Task complexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-2.438*	.155	.000	-2.767	-2.108
2	1	2.438*	.155	.000	2.108	2.767

Basiert auf den geschätzten Randmitteln

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

a. Anpassung für Mehrfachvergleiche: Bonferroni.

Paarweise Vergleiche

Maß:MASS_1

(I) Interfacecomplexity	(J) Interfacecomplexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a]	
					Untergrenze	Obergrenze
1	2	-.188	.167	.279	-.543	.168
2	1	.188	.167	.279	-.168	.543

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Bonferroni.

Errors

Kolmogorov-Smirnov

Tests auf Normalverteilung[b,c,d,e,f,g,h]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistik	df	Signifikanz	Statistik	df	Signifikanz
P1_TaskL_InterfaceL	.536	16	.000	.273	16	.000
P1_TaskH_InterfaceL	.536	16	.000	.273	16	.000
P2_TaskL_InterfaceL	.518	16	.000	.398	16	.000
P2_TaskL_InterfaceH	.448	16	.000	.587	16	.000
P2_TaskH_InterfaceH	.536	16	.000	.273	16	.000
P3_TaskH_InterfaceL	.536	16	.000	.273	16	.000
P4_TaskL_InterfaceH	.518	16	.000	.398	16	.000
P4_TaskH_InterfaceL	.536	16	.000	.273	16	.000
P4_TaskH_InterfaceH	.492	16	.000	.484	16	.000

a. Signifikanzkorrektur nach Lilliefors

b. P1_TaksL_InterfaceH ist konstant und wurde weggelassen.

c. P1_TaskH_InterfaceH ist konstant und wurde weggelassen.

d. P2_TaskH_InterfaceL ist konstant und wurde weggelassen.

e. P3_TaskL_InterfaceL ist konstant und wurde weggelassen.

f. P3_TaskL_InterfaceH ist konstant und wurde weggelassen.

g. P3_TaskH_InterfaceH ist konstant und wurde weggelassen.

h. P4_TaskL_InterfaceL ist konstant und wurde weggelassen.

ANOVA

Mauchly-Test auf Sphärizität[b]

Maß:MASS_1

Innersubjekteffekt	Mauchly-W	Approximiertes Chi-Quadrat	df	Signifikanz	Epsilon[a] Greenhouse-Geisser
Prototype	.302	16.449	5	.006	.600
Taskcomplexity	1.000	.000	0	.	1.000
Interfacecomplexity	1.000	.000	0	.	1.000
Prototype * ...	.326	15.385	5	.009	.710
Prototype * ...	.272	17.864	5	.003	.613
Taskcomplexity * ...	1.000	.000	0	.	1.000
Prototype * Taskcomplexity * ...	.332	15.131	5	.010	.703

Prüft die Nullhypothese, daß sich die Fehlerkovarianz-Matrix der orthonormalisierten transformierten abhängigen Variablen proportional zur Einheitsmatrix verhält.

a. Kann zum Korrigieren der Freiheitsgrade für die gemittelten Signifikanztests verwendet werden. In der Tabelle mit den Tests der Effekte innerhalb der Subjekte werden korrigierte Tests angezeigt.

b. Design: Konstanter Term
Innersubjektdesign: Prototype + Taskcomplexity + Interfacecomplexity + Prototype * Taskcomplexity + Prototype * Interfacecomplexity + Taskcomplexity * Interfacecomplexity + Prototype * Taskcomplexity * Interfacecomplexity

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Prototype	Sphärizität angenommen	.512	3	.171
	Greenhouse-Geisser	.512	1.799	.284
	Huynh-Feldt	.512	2.029	.252
	Untergrenze	.512	1.000	.512
Fehler(Prototype)	Sphärizität angenommen	3.926	45	.087
	Greenhouse-Geisser	3.926	26.981	.145
	Huynh-Feldt	3.926	30.429	.129
	Untergrenze	3.926	15.000	.262
Taskcomplexity	Sphärizität angenommen	.035	1	.035
	Greenhouse-Geisser	.035	1.000	.035
	Huynh-Feldt	.035	1.000	.035
	Untergrenze	.035	1.000	.035
Fehler(Taskcomplexity)	Sphärizität angenommen	.777	15	.052
	Greenhouse-Geisser	.777	15.000	.052
	Huynh-Feldt	.777	15.000	.052
	Untergrenze	.777	15.000	.052
Interfacecomplexity	Sphärizität angenommen	.098	1	.098
	Greenhouse-Geisser	.098	1.000	.098
	Huynh-Feldt	.098	1.000	.098
	Untergrenze	.098	1.000	.098
Fehler (Interfacecomplexity)	Sphärizität angenommen	.965	15	.064
	Greenhouse-Geisser	.965	15.000	.064
	Huynh-Feldt	.965	15.000	.064
	Untergrenze	.965	15.000	.064
Prototype * Taskcomplexity	Sphärizität angenommen	.605	3	.202
	Greenhouse-Geisser	.605	2.131	.284
	Huynh-Feldt	.605	2.494	.243
	Untergrenze	.605	1.000	.605
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen	1.832	45	.041
	Greenhouse-Geisser	1.832	31.963	.057
	Huynh-Feldt	1.832	37.408	.049
	Untergrenze	1.832	15.000	.122
Prototype * Interfacecomplexity	Sphärizität angenommen	.480	3	.160
	Greenhouse-Geisser	.480	1.839	.261
	Huynh-Feldt	.480	2.084	.231
	Untergrenze	.480	1.000	.480

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Prototype	Sphärizität angenommen	1.955	.134
	Greenhouse-Geisser	1.955	.164
	Huynh-Feldt	1.955	.158
	Untergrenze	1.955	.182
Fehler(Prototype)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity	Sphärizität angenommen	.678	.423
	Greenhouse-Geisser	.678	.423
	Huynh-Feldt	.678	.423
	Untergrenze	.678	.423
Fehler(Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Interfacecomplexity	Sphärizität angenommen	1.518	.237
	Greenhouse-Geisser	1.518	.237
	Huynh-Feldt	1.518	.237
	Untergrenze	1.518	.237
Fehler (Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity	Sphärizität angenommen	4.957	.005
	Greenhouse-Geisser	4.957	.012
	Huynh-Feldt	4.957	.008
	Untergrenze	4.957	.042
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Interfacecomplexity	Sphärizität angenommen	1.531	.219
	Greenhouse-Geisser	1.531	.234
	Huynh-Feldt	1.531	.232
	Untergrenze	1.531	.235

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen	4.707	45	.105
	Greenhouse-Geisser	4.707	27.588	.171
	Huynh-Feldt	4.707	31.260	.151
	Untergrenze	4.707	15.000	.314
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.035	1	.035
	Greenhouse-Geisser	.035	1.000	.035
	Huynh-Feldt	.035	1.000	.035
	Untergrenze	.035	1.000	.035
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	.527	15	.035
	Greenhouse-Geisser	.527	15.000	.035
	Huynh-Feldt	.527	15.000	.035
	Untergrenze	.527	15.000	.035
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.043	3	.014
	Greenhouse-Geisser	.043	2.109	.020
	Huynh-Feldt	.043	2.462	.017
	Untergrenze	.043	1.000	.043
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	1.645	45	.037
	Greenhouse-Geisser	1.645	31.629	.052
	Huynh-Feldt	1.645	36.928	.045
	Untergrenze	1.645	15.000	.110

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	1.000	.333
	Greenhouse-Geisser	1.000	.333
	Huynh-Feldt	1.000	.333
	Untergrenze	1.000	.333
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	.392	.759
	Greenhouse-Geisser	.392	.690
	Huynh-Feldt	.392	.721
	Untergrenze	.392	.541
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-.094	.060	.138	-.221	.034

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	3	.016	.036	.669	-.061	.092
	4	-.062*	.028	.041	-.122	-.003
2	1	.094	.060	.138	-.034	.221
	3	.109	.060	.089	-.019	.238
	4	.031	.072	.669	-.122	.184
3	1	-.016	.036	.669	-.092	.061
	2	-.109	.060	.089	-.238	.019
	4	-.078	.044	.096	-.172	.016
4	1	.062*	.028	.041	.003	.122
	2	-.031	.072	.669	-.184	.122
	3	.078	.044	.096	-.016	.172

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Task complexity	(J) Task complexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	.023	.028	.423	-.037	.084
2	1	-.023	.028	.423	-.084	.037

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

Paarweise Vergleiche

Maß:MASS_1

(I) Interfacecomplexity	(J) Interfacecomplexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a]	
					Untergrenze	Obergrenze
1	2	-.039	.032	.237	-.107	.029
2	1	.039	.032	.237	-.029	.107

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

Execution Time

Kolmogorov-Smirnov

Tests auf Normalverteilung

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistik	df	Signifikanz	Statistik	df	Signifikanz
P1_TaskL_InterfaceL	.122	16	.200*	.971	16	.855
P1_TaksL_InterfaceH	.112	16	.200*	.971	16	.858
P1_TaskH_InterfaceL	.140	16	.200*	.955	16	.581
P1_TaskH_InterfaceH	.160	16	.200*	.854	16	.015
P2_TaskL_InterfaceL	.154	16	.200*	.911	16	.123
P2_TaskL_InterfaceH	.246	16	.010	.822	16	.005
P2_TaskH_InterfaceL	.187	16	.140	.956	16	.598
P2_TaskH_InterfaceH	.107	16	.200*	.970	16	.834
P3_TaskL_InterfaceL	.164	16	.200*	.925	16	.206
P3_TaskL_InterfaceH	.156	16	.200*	.909	16	.111
P3_TaskH_InterfaceL	.295	16	.001	.878	16	.036
P3_TaskH_InterfaceH	.108	16	.200*	.973	16	.890
P4_TaskL_InterfaceL	.230	16	.024	.799	16	.003
P4_TaskL_InterfaceH	.157	16	.200*	.913	16	.129
P4_TaskH_InterfaceL	.192	16	.116	.911	16	.122
P4_TaskH_InterfaceH	.111	16	.200*	.934	16	.281

a. Signifikanzkorrektur nach Lilliefors

*. Dies ist eine untere Grenze der echten Signifikanz.

ANOVA

Mauchly-Test auf Sphärizität[b]

Maß:MASS_1

Innersubjekteffekt	Mauchly-W	Approximiertes Chi-Quadrat	df	Signifikanz	Epsilon[a] Greenhouse-Geisser
Prototype	.593	7.171	5	.209	.777
Taskcomplexity	1.000	.000	0	.	1.000
Interfacecomplexity	1.000	.000	0	.	1.000
Prototype * …	.896	1.511	5	.912	.927
Prototype * …	.380	13.262	5	.021	.743
Taskcomplexity * …	1.000	.000	0	.	1.000
Prototype * Taskcomplexity * …	.699	4.910	5	.428	.832

Prüft die Nullhypothese, daß sich die Fehlerkovarianz-Matrix der orthonormalisierten transformierten abhängigen Variablen proportional zur Einheitsmatrix verhält.

a. Kann zum Korrigieren der Freiheitsgrade für die gemittelten Signifikanztests verwendet werden. In der Tabelle mit den Tests der Effekte innerhalb der Subjekte werden korrigierte Tests angezeigt.

b. Design: Konstanter Term
Innersubjektdesign: Prototype + Taskcomplexity + Interfacecomplexity + Prototype * Taskcomplexity + Prototype * Interfacecomplexity + Taskcomplexity * Interfacecomplexity + Prototype * Taskcomplexity * Interfacecomplexity

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Prototype	Sphärizität angenommen	33.659	.000
	Greenhouse-Geisser	33.659	.000
	Huynh-Feldt	33.659	.000
	Untergrenze	33.659	.000
Fehler(Prototype)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity	Sphärizität angenommen	381.272	.000
	Greenhouse-Geisser	381.272	.000
	Huynh-Feldt	381.272	.000
	Untergrenze	381.272	.000
Fehler(Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Interfacecomplexity	Sphärizität angenommen	72.475	.000
	Greenhouse-Geisser	72.475	.000
	Huynh-Feldt	72.475	.000
	Untergrenze	72.475	.000
Fehler (Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity	Sphärizität angenommen	7.571	.000
	Greenhouse-Geisser	7.571	.001
	Huynh-Feldt	7.571	.000
	Untergrenze	7.571	.015
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Interfacecomplexity	Sphärizität angenommen	13.965	.000
	Greenhouse-Geisser	13.965	.000
	Huynh-Feldt	13.965	.000
	Untergrenze	13.965	.002

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Prototype	Sphärizität angenommen	1.488E10	3	4.961E9
	Greenhouse-Geisser	1.488E10	2.331	6.385E9
	Huynh-Feldt	1.488E10	2.786	5.342E9
	Untergrenze	1.488E10	1.000	1.488E10
Fehler(Prototype)	Sphärizität angenommen	6.633E9	45	1.474E8
	Greenhouse-Geisser	6.633E9	34.965	1.897E8
	Huynh-Feldt	6.633E9	41.791	1.587E8
	Untergrenze	6.633E9	15.000	4.422E8
Taskcomplexity	Sphärizität angenommen	2.982E10	1	2.982E10
	Greenhouse-Geisser	2.982E10	1.000	2.982E10
	Huynh-Feldt	2.982E10	1.000	2.982E10
	Untergrenze	2.982E10	1.000	2.982E10
Fehler(Taskcomplexity)	Sphärizität angenommen	1.173E9	15	7.822E7
	Greenhouse-Geisser	1.173E9	15.000	7.822E7
	Huynh-Feldt	1.173E9	15.000	7.822E7
	Untergrenze	1.173E9	15.000	7.822E7
Interfacecomplexity	Sphärizität angenommen	7.729E9	1	7.729E9
	Greenhouse-Geisser	7.729E9	1.000	7.729E9
	Huynh-Feldt	7.729E9	1.000	7.729E9
	Untergrenze	7.729E9	1.000	7.729E9
Fehler (Interfacecomplexity)	Sphärizität angenommen	1.600E9	15	1.066E8
	Greenhouse-Geisser	1.600E9	15.000	1.066E8
	Huynh-Feldt	1.600E9	15.000	1.066E8
	Untergrenze	1.600E9	15.000	1.066E8
Prototype * Taskcomplexity	Sphärizität angenommen	1.483E9	3	4.944E8
	Greenhouse-Geisser	1.483E9	2.782	5.332E8
	Huynh-Feldt	1.483E9	3.000	4.944E8
	Untergrenze	1.483E9	1.000	1.483E9
Fehler (Prototype*Taskcomplexity)	Sphärizität angenommen	2.939E9	45	6.530E7
	Greenhouse-Geisser	2.939E9	41.729	7.042E7
	Huynh-Feldt	2.939E9	45.000	6.530E7
	Untergrenze	2.939E9	15.000	1.959E8
Prototype * Interfacecomplexity	Sphärizität angenommen	2.885E9	3	9.617E8
	Greenhouse-Geisser	2.885E9	2.230	1.294E9
	Huynh-Feldt	2.885E9	2.637	1.094E9
	Untergrenze	2.885E9	1.000	2.885E9

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		Quadratsumme vom Typ III	df	Mittel der Quadrate
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen	3.099E9	45	6.887E7
	Greenhouse-Geisser	3.099E9	33.448	9.265E7
	Huynh-Feldt	3.099E9	39.559	7.834E7
	Untergrenze	3.099E9	15.000	2.066E8
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	8.196E8	1	8.196E8
	Greenhouse-Geisser	8.196E8	1.000	8.196E8
	Huynh-Feldt	8.196E8	1.000	8.196E8
	Untergrenze	8.196E8	1.000	8.196E8
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	6.367E8	15	4.245E7
	Greenhouse-Geisser	6.367E8	15.000	4.245E7
	Huynh-Feldt	6.367E8	15.000	4.245E7
	Untergrenze	6.367E8	15.000	4.245E7
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	3.185E8	3	1.062E8
	Greenhouse-Geisser	3.185E8	2.495	1.277E8
	Huynh-Feldt	3.185E8	3.000	1.062E8
	Untergrenze	3.185E8	1.000	3.185E8
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen	2.383E9	45	5.296E7
	Greenhouse-Geisser	2.383E9	37.421	6.368E7
	Huynh-Feldt	2.383E9	45.000	5.296E7
	Untergrenze	2.383E9	15.000	1.589E8

Tests der Innersubjekteffekte

Maß:MASS_1

Quelle		F	Signifikanz
Fehler (Prototype*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	19.309	.001
	Greenhouse-Geisser	19.309	.001
	Huynh-Feldt	19.309	.001
	Untergrenze	19.309	.001
Fehler (Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		
Prototype * Taskcomplexity * Interfacecomplexity	Sphärizität angenommen	2.005	.127
	Greenhouse-Geisser	2.005	.139
	Huynh-Feldt	2.005	.127
	Untergrenze	2.005	.177
Fehler (Prototype*Taskcomplexity*Interfacecomplexity)	Sphärizität angenommen		
	Greenhouse-Geisser		
	Huynh-Feldt		
	Untergrenze		

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-5347.609	2607.291	.058	-10904.918	209.699

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Prototype	(J) Prototype	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	3	5292.375*	1412.211	.002	2282.319	8302.431
	4	15298.250*	2045.400	.000	10938.583	19657.917
2	1	5347.609	2607.291	.058	-209.699	10904.918
	3	10639.984*	2246.121	.000	5852.491	15427.478
	4	20645.859*	2547.990	.000	15214.947	26076.772
3	1	-5292.375*	1412.211	.002	-8302.431	-2282.319
	2	-10639.984*	2246.121	.000	-15427.478	-5852.491
	4	10005.875*	1767.392	.000	6238.767	13772.983
4	1	-15298.250*	2045.400	.000	-19657.917	-10938.583
	2	-20645.859*	2547.990	.000	-26076.772	-15214.947
	3	-10005.875*	1767.392	.000	-13772.983	-6238.767

Basiert auf den geschätzten Randmitteln

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

Paarweise Vergleiche

Maß:MASS_1

(I) Task complexity	(J) Task complexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-21586.383*	1105.509	.000	-23942.720	-19230.046
2	1	21586.383*	1105.509	.000	19230.046	23942.720

Basiert auf den geschätzten Randmitteln

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

Paarweise Vergleiche

Maß:MASS_1

(I) Interfacecomplexity	(J) Interfacecomplexity	Mittlere Differenz (I-J)	Standardfehler	Signifikanz[a]	95% Konfidenzintervall für die Differenz[a] Untergrenze	Obergrenze
1	2	-10989.617*	1290.885	.000	-13741.073	-8238.161
2	1	10989.617*	1290.885	.000	8238.161	13741.073

Basiert auf den geschätzten Randmitteln

*. Die mittlere Differenz ist auf dem Niveau .05 signifikant

a. Anpassung für Mehrfachvergleiche: Geringste signifikante Differenz (entspricht keinen Anpassungen).

Second User Study: Action and Objects

- Modified IBM Questionnaire (also applicable for 3. user study)
- Closing Questionnaire
- SPSS Output (only relevant tables)

Participant	[Bitte auswählen]
Prototype	[Bitte auswählen]

1. Please answer the following questions concerning the presented prototype:

	-3	-2	-1	0	+1	+2	+3	NA
It was simple to use this design	○	○	○	○	○	○	○	○
I am able to complete my work quickly using this design	○	○	○	○	○	○	○	○
I am able to efficiently complete my work using this design	○	○	○	○	○	○	○	○
It was easy to learn to use this design	○	○	○	○	○	○	○	○
I believe I became productive quickly using this design	○	○	○	○	○	○	○	○
Whenever I make a mistake using the design, I recover easily and quickly	○	○	○	○	○	○	○	○
The organization of information on the mobile interface is clear	○	○	○	○	○	○	○	○
The organization of information on the physical interface is clear	○	○	○	○	○	○	○	○
I like using the interface of this design	○	○	○	○	○	○	○	○
This design has all the functions and capabilities I expect it to have	○	○	○	○	○	○	○	○
Overall, I am satisfied with this design	○	○	○	○	○	○	○	○

2. Positive Comments About the Prototype

1	
2	
3	

3. Negative Comments About the Prototype

1	
2	
3	

4. Any other comments on this prototype?

Munich City Guide - Abschluss-Fragebogen

Teilnehmer: ________

1. **Welches Design war für die Durchführung der Aufgabe insgesamt am besten geeignet?**
    - o Single-Tag Interaction
    - o Multi-Tag Interaction 1 (Sehenswürdigkeiten als tags, Aktionen auf dem Handy)
    - o Multi-Tag Interaction 2 (Sehenswürdigkeiten auf dem Handy, Aktionen als tags)
    - o Multi-Tag Interaction 3 (Sehenswürdigkeiten und Aktionen als separate tags)
    - o Multi-Tag Interaction 4 (Sehenswürdigkeiten und Aktionen als kombinierte tags)

    Warum? Welche Vorteile hat dieses Design?

2. **Welches Design war für die Durchführung der Aufgabe insgesamt am wenigsten geeignet?**
    - o Single-Tag Interaction
    - o Multi-Tag Interaction 1 (Sehenswürdigkeiten als tags, Aktionen auf dem Handy)
    - o Multi-Tag Interaction 2 (Sehenswürdigkeiten auf dem Handy, Aktionen als tags)
    - o Multi-Tag Interaction 3 (Sehenswürdigkeiten und Aktionen als separate tags)
    - o Multi-Tag Interaction 4 (Sehenswürdigkeiten und Aktionen als kombinierte tags)

    Warum? Welche Nachteile hat dieses Design?

3. **Welche Art der Interaktion bevorzugen Sie für die Durchführung der Aufgabe?**
    - o Auf dem Handy (Interaktion mit regulären Handy-Interfaces)
    - o Auf dem Poster (separate oder kombinierte tags)
    - o Auf beidem (z.B. Auswahl einer Sehenswürdigkeit auf dem Poster, Aufrufen einer Aktion auf dem Handy oder umgekehrt)

    Warum? Welche Vorteile hat dieses Design?

4. **Bevorzugen Sie bei der Interaktion mit Tags auf dem Poster die Kombination von mehreren separaten Tags oder die einfache Interaktion mit kombinierten Tags?**
    - o Kombination separater tags (Multi-Tag 3, z.B. Sehenswürdigkeit => Info)
    - o Auswahl kombinierter tags (Multi-Tag 4, z.B. Email-Tag für Hofgarten, Frauenkirche, …)

    Warum? Welche Vorteile hat dieses Design?

5. **Welche Art der Interaktion (auf dem Handy, auf dem Poster oder auf beidem) ist für folgende Teile der Anwendung am besten geeignet?**
    - Starten der Anwendung =>
    - Auswahl einzelner Objekte (z.B. Sehenswürdigkeiten) =>
    - Auswahl und Anwendung einzelner Aktionen (z.B. eine Email schicken) =>
    - Kombination von Objekten und Aktionen =>
    - Beenden der Anwendung (z.B. submit) =>
    - Korrektur von Fehlern =>
    - Hinweise und Hilfe zur Bedienung des Systems =>

6. **Wie intuitiv war die Kombination von Aktionen und Objekten? Wo und wie könnten Hinweise zur Bedienung der einzelnen Prototypen gegeben werden?**

7. **Bei welchem Design traten Schwierigkeiten auf? Welche?**

8. **Verbesserungsvorschläge oder Kommentare zu den einzelnen Designs?**

Attention Shifts

Kolmogorov-Smirnov

Tests of Normality[b,c,d,e,f]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P2_Route	.290	15	.001	.771	15	.002
P2_Email	.535	15	.000	.284	15	.000
P3_Info	.535	15	.000	.284	15	.000
P3_Route	.514	15	.000	.413	15	.000
P3_Email	.514	15	.000	.413	15	.000
P4_Info	.419	15	.000	.603	15	.000
P4_Route	.239	15	.021	.805	15	.004
P4_Email	.316	15	.000	.790	15	.003
P5_Route	.263	15	.006	.868	15	.031
P5_Email	.535	15	.000	.284	15	.000

a. Lilliefors Significance Correction

b. P1_Info is constant. It has been omitted.

c. P1_Route is constant. It has been omitted.

d. P1_Email is constant. It has been omitted.

e. P2_Info is constant. It has been omitted.

f. P5_Info is constant. It has been omitted.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser
Design	.072	32.704	9	.000	.489
Task	.466	9.920	2	.007	.652
Design * Task	.000	110.651	35	.000	.315

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]	
	Huynh-Feldt	Lower-bound
Design	.567	.250
Task	.692	.500
Design * Task	.390	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	439.316	4	109.829
	Greenhouse-Geisser	439.316	1.955	224.671
	Huynh-Feldt	439.316	2.269	193.607
	Lower-bound	439.316	1.000	439.316
Error(Design)	Sphericity Assumed	70.951	56	1.267
	Greenhouse-Geisser	70.951	27.375	2.592
	Huynh-Feldt	70.951	31.767	2.233
	Lower-bound	70.951	14.000	5.068
Task	Sphericity Assumed	265.129	2	132.564
	Greenhouse-Geisser	265.129	1.304	203.325
	Huynh-Feldt	265.129	1.383	191.696
	Lower-bound	265.129	1.000	265.129
Error(Task)	Sphericity Assumed	37.138	28	1.326
	Greenhouse-Geisser	37.138	18.256	2.034
	Huynh-Feldt	37.138	19.363	1.918
	Lower-bound	37.138	14.000	2.653
Design * Task	Sphericity Assumed	102.738	8	12.842
	Greenhouse-Geisser	102.738	2.520	40.764
	Huynh-Feldt	102.738	3.119	32.940
	Lower-bound	102.738	1.000	102.738
Error(Design*Task)	Sphericity Assumed	100.996	112	.902
	Greenhouse-Geisser	100.996	35.284	2.862
	Huynh-Feldt	100.996	43.665	2.313
	Lower-bound	100.996	14.000	7.214

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	86.685	.000
	Greenhouse-Geisser	86.685	.000
	Huynh-Feldt	86.685	.000
	Lower-bound	86.685	.000
Task	Sphericity Assumed	99.947	.000
	Greenhouse-Geisser	99.947	.000
	Huynh-Feldt	99.947	.000
	Lower-bound	99.947	.000
Design * Task	Sphericity Assumed	14.242	.000
	Greenhouse-Geisser	14.242	.000
	Huynh-Feldt	14.242	.000
	Lower-bound	14.242	.002

Pairwise Comparisons

Measure:MEASURE_1

					95% Confidence Interval for Difference[a]	
(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-3.244*	.158	.000	-3.769	-2.720
	3	-2.178*	.085	.000	-2.461	-1.894
	4	-4.200*	.300	.000	-5.196	-3.204
	5	-2.422*	.170	.000	-2.989	-1.855
2	1	3.244*	.158	.000	2.720	3.769
	3	1.067*	.190	.001	.434	1.699
	4	-.956	.347	.156	-2.110	.199
	5	.822*	.189	.007	.193	1.452
3	1	2.178*	.085	.000	1.894	2.461
	2	-1.067*	.190	.001	-1.699	-.434
	4	-2.022*	.336	.000	-3.139	-.906
	5	-.244	.212	1.000	-.949	.461
4	1	4.200*	.300	.000	3.204	5.196
	2	.956	.347	.156	-.199	2.110
	3	2.022*	.336	.000	.906	3.139
	5	1.778*	.249	.000	.949	2.606
5	1	2.422*	.170	.000	1.855	2.989
	2	-.822*	.189	.007	-1.452	-.193
	3	.244	.212	1.000	-.461	.949
	4	-1.778*	.249	.000	-2.606	-.949

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-2.587*	.231	.000	-3.215	-1.958
	3	-.760*	.102	.000	-1.037	-.483
2	1	2.587*	.231	.000	1.958	3.215
	3	1.827*	.206	.000	1.268	2.385
3	1	.760*	.102	.000	.483	1.037
	2	-1.827*	.206	.000	-2.385	-1.268

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Errors

Kolmogorov-Smirnov

Tests of Normality[b,c,d,e]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P1_Info	.535	15	.000	.284	15	.000
P1_Route	.485	15	.000	.499	15	.000
P1_Email	.514	15	.000	.413	15	.000
P2_Route	.485	15	.000	.499	15	.000
P3_Info	.514	15	.000	.413	15	.000
P3_Route	.485	15	.000	.499	15	.000
P3_Email	.514	15	.000	.413	15	.000
P4_Route	.535	15	.000	.284	15	.000
P4_Email	.453	15	.000	.561	15	.000
P5_Route	.535	15	.000	.284	15	.000
P5_Email	.535	15	.000	.284	15	.000

a. Lilliefors Significance Correction

b. P2_Info is constant. It has been omitted.

c. P2_Email is constant. It has been omitted.

d. P4_Info is constant. It has been omitted.

e. P5_Info is constant. It has been omitted.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]
					Greenhouse-Geisser
Design	.454	9.801	9	.371	.734
Task	.852	2.075	2	.354	.871
Design * Task	.017	45.205	35	.146	.630

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]	
	Huynh-Feldt	Lower-bound
Design	.950	.250
Task	.985	.500
Design * Task	1.000	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	.382	4	.096
	Greenhouse-Geisser	.382	2.936	.130
	Huynh-Feldt	.382	3.799	.101
	Lower-bound	.382	1.000	.382
Error(Design)	Sphericity Assumed	4.951	56	.088
	Greenhouse-Geisser	4.951	41.098	.120
	Huynh-Feldt	4.951	53.185	.093
	Lower-bound	4.951	14.000	.354
Task	Sphericity Assumed	.462	2	.231
	Greenhouse-Geisser	.462	1.743	.265
	Huynh-Feldt	.462	1.970	.235
	Lower-bound	.462	1.000	.462
Error(Task)	Sphericity Assumed	2.471	28	.088
	Greenhouse-Geisser	2.471	24.400	.101
	Huynh-Feldt	2.471	27.575	.090
	Lower-bound	2.471	14.000	.177
Design * Task	Sphericity Assumed	.738	8	.092
	Greenhouse-Geisser	.738	5.039	.146
	Huynh-Feldt	.738	8.000	.092
	Lower-bound	.738	1.000	.738
Error(Design*Task)	Sphericity Assumed	10.329	112	.092
	Greenhouse-Geisser	10.329	70.541	.146
	Huynh-Feldt	10.329	112.000	.092
	Lower-bound	10.329	14.000	.738

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	1.081	.375
	Greenhouse-Geisser	1.081	.367
	Huynh-Feldt	1.081	.374
	Lower-bound	1.081	.316
Task	Sphericity Assumed	2.619	.091
	Greenhouse-Geisser	2.619	.099
	Huynh-Feldt	2.619	.092
	Lower-bound	2.619	.128
Design * Task	Sphericity Assumed	1.000	.440
	Greenhouse-Geisser	1.000	.425
	Huynh-Feldt	1.000	.440
	Lower-bound	1.000	.334

Pairwise Comparisons

Measure:MEASURE_1

(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.067	.074	1.000	-.180	.313
	3	-.022	.083	1.000	-.297	.253
	4	.022	.051	1.000	-.148	.192
	5	.089	.051	1.000	-.081	.259
2	1	-.067	.074	1.000	-.313	.180
	3	-.089	.069	1.000	-.318	.140
	4	-.044	.055	1.000	-.228	.139
	5	.022	.051	1.000	-.148	.192
3	1	.022	.083	1.000	-.253	.297
	2	.089	.069	1.000	-.140	.318
	4	.044	.072	1.000	-.194	.283
	5	.111	.062	.961	-.096	.318
4	1	-.022	.051	1.000	-.192	.148
	2	.044	.055	1.000	-.139	.228
	3	-.044	.072	1.000	-.283	.194
	5	.067	.048	1.000	-.094	.227
5	1	-.089	.051	1.000	-.259	.081
	2	-.022	.051	1.000	-.192	.148
	3	-.111	.062	.961	-.318	.096
	4	-.067	.048	1.000	-.227	.094

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.107*	.038	.044	-.211	-.002
	3	-.080	.055	.493	-.228	.068
2	1	.107*	.038	.044	.002	.211
	3	.027	.051	1.000	-.112	.166
3	1	.080	.055	.493	-.068	.228
	2	-.027	.051	1.000	-.166	.112

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Execution Time

Kolmogorov-Smirnov

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P1_Info	.201	15	.104	.903	15	.104
P1_Route	.117	15	.200*	.939	15	.372
P1_Email	.231	15	.030	.816	15	.006
P2_Info	.287	15	.002	.572	15	.000
P2_Route	.230	15	.032	.864	15	.027
P2_Email	.173	15	.200*	.929	15	.264
P3_Info	.164	15	.200*	.873	15	.038
P3_Route	.281	15	.002	.825	15	.008
P3_Email	.250	15	.013	.825	15	.008
P4_Info	.207	15	.084	.789	15	.003
P4_Route	.180	15	.200*	.946	15	.462
P4_Email	.190	15	.152	.851	15	.018
P5_Info	.233	15	.028	.730	15	.001
P5_Route	.234	15	.027	.921	15	.197
P5_Email	.184	15	.186	.942	15	.404

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]
					Greenhouse-Geisser
Design	.352	12.957	9	.168	.688
Task	.863	1.918	2	.383	.879
Design * Task	.016	46.214	35	.124	.593

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]	
	Huynh-Feldt	Lower-bound
Design	.873	.250
Task	.996	.500
Design * Task	.935	.125

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	4.092E9	4	1.023E9
	Greenhouse-Geisser	4.092E9	2.752	1.487E9
	Huynh-Feldt	4.092E9	3.492	1.172E9
	Lower-bound	4.092E9	1.000	4.092E9
Error(Design)	Sphericity Assumed	2.224E9	56	39714180.240
	Greenhouse-Geisser	2.224E9	38.523	57732134.695
	Huynh-Feldt	2.224E9	48.882	45497521.803
	Lower-bound	2.224E9	14.000	1.589E8
Task	Sphericity Assumed	1.075E10	2	5.375E9
	Greenhouse-Geisser	1.075E10	1.759	6.112E9
	Huynh-Feldt	1.075E10	1.992	5.397E9
	Lower-bound	1.075E10	1.000	1.075E10
Error(Task)	Sphericity Assumed	9.769E8	28	34890626.386
	Greenhouse-Geisser	9.769E8	24.623	39675958.431
	Huynh-Feldt	9.769E8	27.885	35034805.126
	Lower-bound	9.769E8	14.000	69781252.773
Design * Task	Sphericity Assumed	1.845E9	8	2.306E8
	Greenhouse-Geisser	1.845E9	4.747	3.887E8
	Huynh-Feldt	1.845E9	7.478	2.467E8
	Lower-bound	1.845E9	1.000	1.845E9
Error(Design*Task)	Sphericity Assumed	4.153E9	112	37082087.542
	Greenhouse-Geisser	4.153E9	66.452	62498721.109
	Huynh-Feldt	4.153E9	104.695	39669348.522
	Lower-bound	4.153E9	14.000	2.967E8

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	25.757	.000
	Greenhouse-Geisser	25.757	.000
	Huynh-Feldt	25.757	.000
	Lower-bound	25.757	.000
Task	Sphericity Assumed	154.039	.000
	Greenhouse-Geisser	154.039	.000
	Huynh-Feldt	154.039	.000
	Lower-bound	154.039	.000
Design * Task	Sphericity Assumed	6.220	.000
	Greenhouse-Geisser	6.220	.000
	Huynh-Feldt	6.220	.000
	Lower-bound	6.220	.026

Pairwise Comparisons

Measure:MEASURE_1

(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	5610.511*	1580.492	.032	354.275	10866.747
	3	-1304.089	1288.316	1.000	-5588.638	2980.460
	4	6777.978*	808.701	.000	4088.483	9467.473
	5	10061.689*	971.818	.000	6829.717	13293.661
2	1	-5610.511*	1580.492	.032	-10866.747	-354.275
	3	-6914.600*	1832.869	.021	-13010.164	-819.036
	4	1167.467	1534.314	1.000	-3935.196	6270.129
	5	4451.178	1420.824	.073	-274.050	9176.405
3	1	1304.089	1288.316	1.000	-2980.460	5588.638
	2	6914.600*	1832.869	.021	819.036	13010.164
	4	8082.067*	1048.017	.000	4596.679	11567.454
	5	11365.778*	1320.341	.000	6974.726	15756.829
4	1	-6777.978*	808.701	.000	-9467.473	-4088.483
	2	-1167.467	1534.314	1.000	-6270.129	3935.196
	3	-8082.067*	1048.017	.000	-11567.454	-4596.679
	5	3283.711	1149.215	.127	-538.229	7105.651
5	1	-10061.689*	971.818	.000	-13293.661	-6829.717
	2	-4451.178	1420.824	.073	-9176.405	274.050
	3	-11365.778*	1320.341	.000	-15756.829	-6974.726
	4	-3283.711	1149.215	.127	-7105.651	538.229

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-16796.187*	1125.710	.000	-19855.591	-13736.782
	3	-6554.947*	908.299	.000	-9023.480	-4086.413
2	1	16796.187*	1125.710	.000	13736.782	19855.591
	3	10241.240*	836.074	.000	7968.994	12513.486
3	1	6554.947*	908.299	.000	4086.413	9023.480
	2	-10241.240*	836.074	.000	-12513.486	-7968.994

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Third User Study: GUI Widgets

- Closing Questionnaire
- SPSS Output (only relevant tables)

Library Search - Abschluss-Fragebogen

Teilnehmer: ________

1. **Welches Design war für die Durchführung der Aufgabe insgesamt am besten geeignet?**
   - o Single-Tag Interaction
   - o Multi-Tag Interaction 1 (Widgets auf dem Handy einzeln über Poster ansteuern)
   - o Multi-Tag Interaction 2 (Auswahl von Optionen direkt über das Poster)

   Warum? Welche Vorteile hat dieses Design?

2. **Welches Design war für die Durchführung der Aufgabe insgesamt am wenigsten geeignet?**
   - o Single-Tag Interaction
   - o Multi-Tag Interaction 1 (Widgets auf dem Handy einzeln über Poster ansteuern)
   - o Multi-Tag Interaction 2 (Auswahl von Optionen direkt über das Poster)

   Warum? Welche Nachteile hat dieses Design?

3. **Welche Art der Interaktion bevorzugen Sie für die Durchführung der Aufgabe?**
   - o Auf dem Handy (Interaktion mit regulären Handy-Interfaces)
   - o Auf dem Poster (Interaktion durch Auswahl von Tags)
   - o Auf beiden (z.B. Berühren eines Tags auf dem Poster öffnet Widget auf Handy)

Warum? Welche Vorteile hat dieses Design?

4. **Bei Multi-Tag Designs wurden einzelne Optionen/Tags als Kreise oder Vierecke dargestellt. Ist Ihnen dies aufgefallen? War für Sie ersichtlich, dass diese Darstellung analog zur Darstellung von Radio Buttons und Checkboxes aus Formularen (z.B. Webseiten) erfolgte und genauso wie diese für die Auswahl einzelner bzw. mehrerer Werte stand? Ist diese Darstellung leicht verständlich? Wenn nein, wie könnte dies besser dargestellt werden?**

5. **Welche Art der Interaktion (auf dem Handy, auf dem Poster oder auf beidem) ist für folgende Teile der Anwendung am besten geeignet?**
    - Starten der Anwendung =>
    - Navigation (Wechsel zwischen den einzelnen Suchoptionen) =>
    - Auswahl einzelner Optionen =>
    - Beenden der Anwendung (z.B. submit) =>
    - Gesamtübersicht, Zusammenfassung =>
    - Korrektur von Fehlern =>
    - Hinweise und Hilfe zur Bedienung des Systems =>

6. **Wie intuitiv war die Interaktion mit dem Poster und den Tags? Wo und wie könnten Hinweise zur Bedienung der einzelnen Prototypen gegeben werden?**

7. Bei welchem Design traten Schwierigkeiten auf? Welche?

8. Verbesserungsvorschläge oder Kommentare zu den einzelnen Designs?

Attention Shifts

Kolmogorov-Smirnov

Tests of Normality[b,c,d]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P2_High	.514	15	.000	.413	15	.000
P3_Low	.300	15	.001	.799	15	.004
P3_High	.245	15	.015	.933	15	.302

a. Lilliefors Significance Correction

b. P1_Low is constant. It has been omitted.

c. P1_High is constant. It has been omitted.

d. P2_Low is constant. It has been omitted.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser
Design	.106	29.138	2	.000	.528
Task	1.000	.000	0	.	1.000
Design * Task	.107	29.103	2	.000	.528

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

	Epsilon[a]	
Within Subjects Effect	Huynh-Feldt	Lower-bound
Design	.535	.500
Task	1.000	1.000
Design * Task	.535	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	2372.622	2	1186.311
	Greenhouse-Geisser	2372.622	1.056	2246.505
	Huynh-Feldt	2372.622	1.069	2218.660
	Lower-bound	2372.622	1.000	2372.622
Error(Design)	Sphericity Assumed	63.378	28	2.263
	Greenhouse-Geisser	63.378	14.786	4.286
	Huynh-Feldt	63.378	14.972	4.233
	Lower-bound	63.378	14.000	4.527
Task	Sphericity Assumed	256.711	1	256.711
	Greenhouse-Geisser	256.711	1.000	256.711
	Huynh-Feldt	256.711	1.000	256.711
	Lower-bound	256.711	1.000	256.711
Error(Task)	Sphericity Assumed	28.622	14	2.044
	Greenhouse-Geisser	28.622	14.000	2.044
	Huynh-Feldt	28.622	14.000	2.044
	Lower-bound	28.622	14.000	2.044
Design * Task	Sphericity Assumed	149.956	2	74.978
	Greenhouse-Geisser	149.956	1.056	141.963
	Huynh-Feldt	149.956	1.070	140.199
	Lower-bound	149.956	1.000	149.956
Error(Design*Task)	Sphericity Assumed	60.711	28	2.168
	Greenhouse-Geisser	60.711	14.788	4.105
	Huynh-Feldt	60.711	14.974	4.054
	Lower-bound	60.711	14.000	4.337

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	524.107	.000
	Greenhouse-Geisser	524.107	.000
	Huynh-Feldt	524.107	.000
	Lower-bound	524.107	.000
Task	Sphericity Assumed	125.565	.000
	Greenhouse-Geisser	125.565	.000
	Huynh-Feldt	125.565	.000
	Lower-bound	125.565	.000
Design * Task	Sphericity Assumed	34.580	.000
	Greenhouse-Geisser	34.580	.000
	Huynh-Feldt	34.580	.000
	Lower-bound	34.580	.000

Pairwise Comparisons

Measure:MEASURE_1

(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-12.133*	.091	.000	-12.380	-11.886
	3	-8.933*	.473	.000	-10.218	-7.649
2	1	12.133*	.091	.000	11.886	12.380
	3	3.200*	.470	.000	1.923	4.477
3	1	8.933*	.473	.000	7.649	10.218
	2	-3.200*	.470	.000	-4.477	-1.923

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-3.378*	.301	.000	-4.024	-2.731
2	1	3.378*	.301	.000	2.731	4.024

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Errors

Kolmogorov-Smirnov

Tests of Normality[b]

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P1_Low	.514	15	.000	.413	15	.000
P1_High	.514	15	.000	.413	15	.000
P2_Low	.514	15	.000	.413	15	.000
P2_High	.453	15	.000	.561	15	.000
P3_High	.350	15	.000	.643	15	.000

a. Lilliefors Significance Correction

b. P3_Low is constant. It has been omitted.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser
Design	.747	3.791	2	.150	.798
Task	1.000	.000	0	.	1.000
Design * Task	.941	.786	2	.675	.945

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]	
	Huynh-Feldt	Lower-bound
Design	.885	.500
Task	1.000	1.000
Design * Task	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	.156	2	.078
	Greenhouse-Geisser	.156	1.596	.097
	Huynh-Feldt	.156	1.769	.088
	Lower-bound	.156	1.000	.156
Error(Design)	Sphericity Assumed	2.844	28	.102
	Greenhouse-Geisser	2.844	22.348	.127
	Huynh-Feldt	2.844	24.768	.115
	Lower-bound	2.844	14.000	.203
Task	Sphericity Assumed	.900	1	.900
	Greenhouse-Geisser	.900	1.000	.900
	Huynh-Feldt	.900	1.000	.900
	Lower-bound	.900	1.000	.900
Error(Task)	Sphericity Assumed	1.933	14	.138
	Greenhouse-Geisser	1.933	14.000	.138
	Huynh-Feldt	1.933	14.000	.138
	Lower-bound	1.933	14.000	.138
Design * Task	Sphericity Assumed	.867	2	.433
	Greenhouse-Geisser	.867	1.889	.459
	Huynh-Feldt	.867	2.000	.433
	Lower-bound	.867	1.000	.867
Error(Design*Task)	Sphericity Assumed	4.800	28	.171
	Greenhouse-Geisser	4.800	26.449	.181
	Huynh-Feldt	4.800	28.000	.171
	Lower-bound	4.800	14.000	.343

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	.766	.475
	Greenhouse-Geisser	.766	.449
	Huynh-Feldt	.766	.461
	Lower-bound	.766	.396
Task	Sphericity Assumed	6.517	.023
	Greenhouse-Geisser	6.517	.023
	Huynh-Feldt	6.517	.023
	Lower-bound	6.517	.023
Design * Task	Sphericity Assumed	2.528	.098
	Greenhouse-Geisser	2.528	.102
	Huynh-Feldt	2.528	.098
	Lower-bound	2.528	.134

Pairwise Comparisons

Measure:MEASURE_1

(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.067	.096	1.000	-.327	.194
	3	-.100	.087	.813	-.337	.137
2	1	.067	.096	1.000	-.194	.327
	3	-.033	.059	1.000	-.194	.127
3	1	.100	.087	.813	-.137	.337
	2	.033	.059	1.000	-.127	.194

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.200*	.078	.023	-.368	-.032
2	1	.200*	.078	.023	.032	.368

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Execution Time

Kolmogorov-Smirnov

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
P1_Low	.257	15	.009	.863	15	.026
P1_High	.198	15	.118	.917	15	.171
P2_Low	.152	15	.200*	.965	15	.782
P2_High	.179	15	.200*	.899	15	.093
P3_Low	.194	15	.135	.930	15	.276
P3_High	.161	15	.200*	.962	15	.723

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

ANOVA

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]
					Greenhouse-Geisser
Design	.506	8.854	2	.012	.669
Task	1.000	.000	0	.	1.000
Design * Task	.702	4.604	2	.100	.770

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Epsilon[a]	
	Huynh-Feldt	Lower-bound
Design	.714	.500
Task	1.000	1.000
Design * Task	.847	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b. Design: Intercept
Within Subjects Design: Design + Task + Design * Task

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square
Design	Sphericity Assumed	4.491E9	2	2.245E9
	Greenhouse-Geisser	4.491E9	1.339	3.355E9
	Huynh-Feldt	4.491E9	1.428	3.145E9
	Lower-bound	4.491E9	1.000	4.491E9
Error(Design)	Sphericity Assumed	6.127E9	28	2.188E8
	Greenhouse-Geisser	6.127E9	18.742	3.269E8
	Huynh-Feldt	6.127E9	19.993	3.065E8
	Lower-bound	6.127E9	14.000	4.377E8
Task	Sphericity Assumed	5.219E9	1	5.219E9
	Greenhouse-Geisser	5.219E9	1.000	5.219E9
	Huynh-Feldt	5.219E9	1.000	5.219E9
	Lower-bound	5.219E9	1.000	5.219E9
Error(Task)	Sphericity Assumed	9.270E8	14	66210765.754
	Greenhouse-Geisser	9.270E8	14.000	66210765.754
	Huynh-Feldt	9.270E8	14.000	66210765.754
	Lower-bound	9.270E8	14.000	66210765.754
Design * Task	Sphericity Assumed	1.549E8	2	77431043.611
	Greenhouse-Geisser	1.549E8	1.541	1.005E8
	Huynh-Feldt	1.549E8	1.694	91410925.652
	Lower-bound	1.549E8	1.000	1.549E8
Error(Design*Task)	Sphericity Assumed	1.559E9	28	55664042.218
	Greenhouse-Geisser	1.559E9	21.567	72266022.980
	Huynh-Feldt	1.559E9	23.718	65713974.491
	Lower-bound	1.559E9	14.000	1.113E8

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		F	Sig.
Design	Sphericity Assumed	10.261	.000
	Greenhouse-Geisser	10.261	.003
	Huynh-Feldt	10.261	.002
	Lower-bound	10.261	.006
Task	Sphericity Assumed	78.825	.000
	Greenhouse-Geisser	78.825	.000
	Huynh-Feldt	78.825	.000
	Lower-bound	78.825	.000
Design * Task	Sphericity Assumed	1.391	.265
	Greenhouse-Geisser	1.391	.265
	Huynh-Feldt	1.391	.266
	Lower-bound	1.391	.258

Pairwise Comparisons

Measure:MEASURE_1

(I) Design	(J) Design	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-15556.367*	4787.422	.017	-28567.409	-2545.324
	3	-1217.367	2290.678	1.000	-7442.868	5008.135
2	1	15556.367*	4787.422	.017	2545.324	28567.409
	3	14339.000*	3949.631	.008	3604.870	25073.130
3	1	1217.367	2290.678	1.000	-5008.135	7442.868
	2	-14339.000*	3949.631	.008	-25073.130	-3604.870

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Pairwise Comparisons

Measure:MEASURE_1

(I) Task	(J) Task	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-15230.222*	1715.430	.000	-18909.454	-11550.990
2	1	15230.222*	1715.430	.000	11550.990	18909.454

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.