Peripheral Interaction

Exploring the Design Space

Dissertation

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ABSTRACT

In our everyday life we carry out a multitude of activities in parallel without focusing our attention explicitly on them. We drink a cup of tea while reading a book, we signal a colleague passing by with a hand gesture, that we are concentrated right now and that he should wait one moment, or we walk a few steps backwards while taking photos. Many of these interactions – like drinking, sending signals via gestures or walking – are rather complex by themselves. By means of learning and training, however, these interactions become part of our routines and habits and therefore only consume little or no attentional resources. In contrast, when interacting with digital devices, we are often asked for our full attention. To carry out – even small and marginal tasks – we are regularly forced to switch windows, do precise interactions (e.g., pointing with the mouse) and thereby these systems trigger context and focus switches, disrupting us in our main focus and task. Peripheral interaction aims at making use of human capabilities and senses like divided attention, spatial memory and proprioception to support interaction with digital devices in the periphery of the attention, consequently quasi-parallel to another primary task.

In this thesis we investigate peripheral interaction in the context of a standard desktop computer environment. We explore three interaction styles for peripheral interaction: graspable interaction, touch input and freehand gestures. *StaTube* investigates graspable interaction in the domain of instant messaging, while the *Appointment Projection* uses simple wiping gestures to access information about upcoming appointments. These two explorations focus on one interaction style each and offer first insights into the general benefits of peripheral interaction. In the following we carried out two studies comparing all three interaction styles (graspable, touch, freehand) for audio player control and for dealing with notifications. We found that all three interaction styles are generally fit for peripheral interaction but come with different advantages and disadvantages. The last set of explorative studies deals with the ability to recall spatial locations in 2D as well as 3D. The *Unadorned Desk* makes use of the physical space around the desktop computer and thereby offers an extended interaction space to store and retrieve virtual items such as commands, applications or tools. Finally, evaluation of peripheral interaction is not straightforward as the systems are designed to blend into the environment and not draw attention on them. We propose an additional evaluation method for the lab to complement the current evaluation practice in the field.

The main contributions of this thesis are (1) an exhaustive classification and a more detailed look at manual peripheral interaction for tangible, touch and freehand interaction. Based on these exploration with all three interaction styles, we offer (2) implications in terms of overall benefits of peripheral interaction, learnability and habituation, visual and mental attention, feedback and handedness for future peripheral interaction design. Finally, derived from a diverse set of user studies, we assess (3) evaluation strategies enriching the design process for peripheral interaction.

ZUSAMMENFASSUNG

In unserem täglichen Leben führen wir eine große Anzahl an Aktivitäten parallel aus ohne uns explizit darauf zu konzentrieren. Wir trinken Tee während wir ein Buch lesen, wir signalisieren einem Kollegen durch eine Handgeste, dass wir gerade konzentriert sind und er einen Moment warten soll oder wir gehen ein paar Schritte rückwärts während wir fotografieren. Viele dieser Aktivitäten – wie beispielsweise Trinken, Gestikulieren und Laufen – sind an sich komplex. Durch Training werden diese Tätigkeiten allerdings Teil unserer Routinen und Gewohnheiten, und beanspruchen daher nur noch wenig oder sogar keine Aufmerksamkeit. Im Gegensatz dazu, verlangen digitale Geräte meist unsere volle Aufmerksamkeit während der Interaktion. Um – oftmals nur kleine – Aufgaben durchzuführen, müssen wir Fenster wechseln, präzise Aktionen durchführen (z.B. mit dem Mauszeiger zielen) und werden dabei durch die Systeme zu einem Kontext- und Fokuswechsel gezwungen. Periphere Interaktion hingegen macht sich menschliche Fähigkeiten wie geteilte Aufmerksamkeit, das räumliche Gedächtnis und Propriozeption zu Nutze um Interaktion mit digitalen Geräten am Rande der Aufmerksamkeit also der Peripherie zu ermöglichen – quasi-parallel zu einem anderen Primärtask.

In dieser Arbeit untersuchen wir Periphere Interaktion am Computerarbeitsplatz. Dabei betrachten wir drei verschiedene Interaktionsstile: Begreifbare Interaktion (graspable), Touch Eingabe und Freiraum Gestik (freehand). *StaTube* untersucht Begreifbare Interaktion am Beispiel von Instant Messaging, während die *Appointment Projection* einfache Wischgesten nutzt, um Informationen nahender Termine verfügbar zu machen. Diese beiden Untersuchungen betrachten jeweils einen Interaktionsstil und beleuchten erste Vorteile, die durch Periphere Interaktion erzielt werden können. Aufbauend darauf führen wir zwei vergleichende Studien zwischen allen drei Interaktionsstilen durch. Als Anwendungsszenarien dienen Musiksteuerung und der Umgang mit Benachrichtigungsfenstern. Alle drei Interaktionsstile können erfolgreich für Periphere Interaktion eingesetzt werden, haben aber verschiedene Vor- und Nachteile. Die letzte Gruppe von Studien befasst sich mit dem räumlichen Gedächtnis in 2D und 3D. Das *Unadorned Desk* nutzt den physikalischen Raum neben dem Desktop Computer um virtuelle Objekte, beispielsweise Funktionen, Anwendungen oder Werkzeuge, zu lagern. Darüber hinaus ist die Evaluation von Peripherer Interaktion anspruchsvoll, da sich die Systeme in die Umwelt integrieren und gerade keine Aufmerksamkeit auf sich ziehen sollen. Wir schlagen eine Evaluationsmethode für das Labor vor, um die derzeitig vorherrschenden Evaluationsmethoden in diesem Forschungsfeld zu ergänzen.

Die Kernbeiträge dieser Arbeit sind eine (1) umfassende Klassifizierung und ein detaillierter Blick auf manuelle Periphere Interaktion, namentlich Begreifbare Interaktion, Touch Eingabe und Freiraum Gestik. Basierend auf unseren Untersuchungen ziehen wir (2) Schlussfolgerungen, die den generellen Nutzen von Peripherer Interaktion darlegen und Bereiche wie die Erlernbarkeit und Gewöhnung, visuelle und mentale Aufmerksamkeit, Feedback so wie Händigkeit beleuchten um zukünftige Projekte im Bereich der Peripheren Interaktion zu unterstützen. Aufbauend auf den verschiedenen Nutzerstudien, diskutieren wir Evaluationsstrategien um den Entwicklungsprozess Peripherer Interaktion zu unterstützen.

PREFACE

Starting my PhD the whole field of Human-Computer Interaction was mine to pick from one single topic. A decision I kindly directed to colleagues to at least pick one out of three topics by voting by a show of hands. And you guys did a great job! After twisting around "Something with Ambient Information" I ended up with Peripheral Interaction (initially called by me "Effortless Interaction"), a new research topic supposedly nobody was working on... Few months later I attended my first conference. Up on stage a researcher suddenly mentioned the term peripheral interaction – **Saskia Bakker**. Somewhere in Eindhoven, and somewhere in Munich two people started to work on the same topic at the same time. We started talking, we started emailing, we started chatting, we met again at conferences, shared hotel rooms, and organized a workshop. I could not have been luckier with this coincidence.

This encounter of Saskia and me might be the most surprising and unforeseen event during the course of my PhD, however, it stands as a sample of people I met and worked (and had a great deal of fun with) during the last four years. Many people therefore influenced my work summarized in this thesis in one way or another. Some of them listed as co-authors of papers throughout this thesis, some contributed more informally and are listed here in the acknowledgments. With this in mind I chose the scientific plural for this thesis to appreciate the wonderful environment I was able to do this work in.

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First and foremost I want to thank **Andreas Butz** for providing support in every undertaking, being it a research idea or "extravaganza" such as lab visits abroad. For offering me great freedom in my work and still being the go-to guy for professional and organizational questions but many topics far beyond that, too. Refusing to stay in academia for now – although I feel honored that you tried so hard to convince me – I really want to stay in close contact with the HCI Group beyond this PhD. Secondly, I want to thank **Elise van den Hoven** for taking on a second peripheral interaction protégé and supporting especially the final stages of my dissertation with not only subject-specific wisdom but offering me an outside perspective on my work and also academia general. After Barcelona, Eindhoven, Cape Town and Munich, I hope we meet again somewhere around the globe.

Thanks so much to my wonderful colleagues (*#weltbestekollegen*) of the Media Informatics and Human-Computer Interaction Group. **Max Maurer** for being a friend before being a colleague and continuing the joint journey after countless lectures and exams to countless office hours and morning breaks while our computers still were slow and needed 15 minutes just to start up. For so many shared projects and solving all my technical problems however small and stupid they were. **Sebastian Boring** for being my third supervisor in disguise from day one and enduring so many paper dramas (and successes ;)) with me. Thanks for being my safety net while being over there in Calgary and continuing to be so present independent of any geographical distance. **Sebastian Löhmann** – or rather tea buddy, coach, bodyguard or just simply Löhmi. Thanks for sharing research interests, the feedback-project-disaster and the monthly appointment that hardly ever happened (you sufficiently made up for that!). This is your official membership card, welcome to the "Sebastians are the Best" club! **Raphael Wimmer**, my first and only work-husband, who would have guessed that after our first encounter. For all deep conversations, especially the one on our flight back from Kingston. Thanks for fixing every broken hardware, but always remember, never ever use a cutter if you have not slept at night, especially when I am not around! **Emanuel – Ema – von Zezschwitz**, the guy who made history, thanks for doing a fabulous job compensating lost office-mates and putting up with my constant stream of words. To compensate leaving you, I need a cardboard face (well eyes and hair are enough ;)) of you to put behind my monitor in my next office for whenever I need somebody to talk to. And do not slide down too much on your chair during the next CHI deadline, this was our special moment! **Fabian Hennecke** for introducing me to the truly important things in life – Buli, Nerfguns, Charlie the Unicorn and T-Rex. How would I survive without your preparation in the real world out there. It is your fault that I am now truly amused by bad jokes. And of course, thanks just for being so cute..! ;) **Hendrik Richter** for sharing the real and secret title of your thesis with me! Thanks for putting up with me ruining every experiment. And most importantly, what's the latest story about A.? **Alina Hang** for sharing hotel rooms all over the world, wearing the same clothes, ordering the same food and making sure I am not the last to finish lunch. And of course, thanks for giving us the chance to make the Internet even better! **Henri Palleis** for entertainment due to unlocked computers and during tea cooking. And especially for not (!) acknowledging my plan to leave the lab. Thanks **Sarah Tausch** for carrying on for me. Teaching "Digitale Medien" and more importantly doing the "Lehrplanung". Keep on following the light! **Alexander De Luca** for the insight scoop on review processes and the statistical wisdom. **Alexander Wiethoff** for lots of joint teaching in the field of interaction design saving me from getting too nerdy. **Simon Stusak** for covering my seminar duties probably more often than I took care of them myself. **Sara Streng** for sharing the phenomenon of a girly topic, and **Bettina Conradi** for the courage to make a decision. **Dominikus Baur** for all the baby talk and building tools for my music logging obsession. **Aurélien Tabard** for an external perspective on my PhD topic and the delicious french sweets. **Gregor Broll** – my bus and sport buddy – and **Richard Atterer** for encouraging me in starting this PhD. It was really good advice, guys! Thanks to our external PhDs **Nora Broy**, **Martin Knobel**, **Felix Lauber**, and **Sonja Rümelin**, who only every now and then appeared, but without them I would not have experienced the world of displays. And keep in mind, in the car everything besides driving is peripheral interaction! Finally, to **Florian Alt**, **Axel Hösl**, **Bernhard Slawik** and **Julie Wagner**, who only started shortly before I finished. Keep up the good spirit in the lab!

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During my PhD I worked with many fantastic students, who all contributed to this thesis in one way or another: **Adalie Hemme**, **Kerstin Holzner**, **Marie Lehmann**, **Xaver Loeffelholz von Colberg**, **Clara Lüling**, **Julia Polleti**, **Simone Rodestock**, **Franziska Straßer**, **Attila von Thermann** and **Christine Wagner**. It was a pleasure discussing and exploring this research field together with you!

I was lucky enough to spend some time at the University of Calgary in Canada. I especially want to thank **Saul Greenberg** for this amazing opportunity and the whole **ILab** for being such a warm and welcoming place and supporting me and my project in every way while I was there.

Last but not least, I thank my **friends** outside of the research community for providing me the perfect balance. Do not go out and start buying your doctor titles now! My **parents** for their support especially through cake deliveries right to my front door – who would survive a PhD without lots of cake! – and their pragmatic perspective on life such as *"Hättest du dich nicht so positiv hervorgetan, dann stündest du jetzt nicht vor der Entscheidung..."* when deciding whether to do a PhD. Finally, I want to thank **Martin**, for probably being the only person outside of the HCI community who understood what I was doing here. For sharing the passion to rant about unusable gadgets, heated discussions about how technology should work and especially for providing a different perspective on things. Thanks so much for supporting every and never questioning any decision I made. I am not going to write *"I could not have done it without you"* but it was so much better with you along the way!

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Chapter 1

Introduction

It is a regular Tuesday morning. Mary just entered the office with her coffee-to-go that she just bought on her way to work. Sitting down at her desk she presses the power button of her computer while putting her coffee and her keys on the desk. The computer turns on and Mary starts checking her e-mails. In one of her mails she is asked to call a colleague in the afternoon. While still focusing on the email explaining the reasons for the call she grabs a pen on her desk and after finishing reading the email takes a note to not forget about the call. Having read through her mails she opens up a report she is currently working on and starts typing. Deep in thoughts about the next paragraph she is going to type, she reaches over to her coffee and takes a sip. Suddenly a window pops up. Her sister is asking her via instant messaging whether she is coming over for dinner on the weekend. Although her sister meant well, she is kind of annoyed by the interruption, as this report is really important and has to be finished before lunch. Although meaning to do so, she had forgotten to set her instant messaging client to "do not disturb" upon start up this morning. She quickly replies to her sister and then clicks on the instant messenger's icon in the task bar and selects the appropriate state in the menu. Switching windows she returns to her report wondering what she was thinking right before the interruption. Later her telephone rings and while closing the report, which she just finished, she already reaches over and picks up the phone while simultaneously clicking on "yes" when the saving dialog appears. Her colleague Peter is calling to ask if she is going to lunch and offers to pick her up in five minutes. Mary decides to return to her inbox as new emails have arrived again and starts to process them until she hears Peter in the hallway. Just as he enters she looks up and greets him while in parallel locking her computer via a keyboard shortcut. She is about to get up when she realizes that her left shoelaces are open. Already engaged in a conversation about Peter's latest holidays, she reaches down and ties them, while looking in parallel at a photo that Peter shows her from his trip. Still absorbed in the conversation, Mary grabs the keys from her desk, takes her bag and walks out of her office together with Peter locking the door behind her.

Similar scenarios are part of everybody's daily life, during professional and personal life. Mary, while being focused on a task (reading emails, writing a report, being engaged in a conversation, etc.), effortlessly carries out several tasks (grabbing a pen, drinking coffee, picking up the phone, tying her shoe laces etc.) in parallel without (or with only minimal) cognitive and visual attention. To interact with the physical world around one in such a way, people easily make use of several human capabilities such as divided attention, proprioception and spatial memory, however, interaction with digital devices usually does not make use of any of these capabilities to facilitate interaction with secondary tasks yet.

1.1 Motivation

The vision of ubiquitous computing [248] describes digital technology embedded into our everyday lives in a seamless way. In fact, technology did find its way into nearly every sphere of life in recent years. It is not only omnipresent in offices or the home, but many people carry around several digital devices wherever they go, offering access to digital data and information anywhere, anytime. However, these devices are far from being seamlessly integrated in our lives but require interactions to be performed in a focused way. This differs greatly from the interactions that we carry out with the physical world, where, as previously described, we carry out all kinds of actions, which we are not focused on during an ordinary day. Drinking a cup of coffee in the morning while in parallel getting ready for work. Meeting a colleague on the way to the office and chatting while keeping on walking and effortlessly finding our way to work. Sitting on the desk, talking on the phone and anticipating an approaching colleague, lifting our hand signaling that we are having an important conversation on the phone and cannot be interrupted without even realizing that we lifted our hand. These are just few examples of peripheral interaction in our everyday lives. Inspired by our human capabilities we here set out to transfer interaction in the periphery from the physical to the digital world.

1.1.1 Current Situation

Multitasking is omnipresent when interacting with digital systems [255], especially with regular computers. People constantly switch between windows and applications, often triggered by external interruptions such as pop-ups informing about new emails or requiring the user's attention for instance to install a new security update. These secondary tasks – which can happen concurrently [52] – not only interrupt and slow down users, but also cause stress and exhaustion [17, 163]. Thus, research in the context of multitasking tries to reduce the effect of such interruptions by finding the best possible timing for interruptions [172]. However, many secondary tasks are internally triggered [61], which also holds true for peripheral tasks [22], hence people themselves decide to switch tasks. Peripheral interaction for digital devices therefore aims at facilitating the interplay between different (sub)tasks – between the physical world and the digital world or while being engaged in two digital tasks.

As peripheral secondary tasks we consider side tasks – related or unrelated to the current primary task – such as skipping a song in an audio player. To do so with current computing systems one is asked to switch windows, point with the mouse to rather small icons and thereby looses focus of the current task. Moreover, while on the move and listening to music on a smart phone, one has to get out the phone from the pocket, unlock it, navigate to the player and press a distinct location on the screen – at least in the worst case scenario. Peripheral interaction hence seeks to explore other means of direct access to important or regularly utilized commands or tasks to minimize interaction time (which significantly reduces errors in the primary task [9]), interruptions, focus switches and cognitive load.

1.1.2 Achieving Peripheral Interaction

Peripheral interaction is inspired by ambient information [197], which is intended to offer information in the periphery of attention. Peripheral interaction extends this vision by not only moving information but also *interaction* to the visual and attentional periphery. Hence, to successfully achieve interaction in the periphery, cognitive and visual load imposed by an interaction should be minimized. We believe that this can be achieved by offering coarse interaction which directly accesses the desired functionality by making use of human capabilities such as divided attention, proprioception and spatial memory. This is especially helpful for small tasks that draw a disproportional amount of attention towards them and thereby impose focus switches.

Referring to the previous example of listening to music at a standard computer or on the go, listening, or more precisely controlling a music player, is one of the very few tasks that can already be directly accessed. Many keyboards offer distinct media keys and many headphones have remote controls attached to the cable for the most common functionalities. Generally, to access functionality more directly on a computer, keyboard shortcuts are offered. However, while the usage of keyboard shortcuts is proven to be very efficient [147], researchers found that they are heavily underused, even by experienced users [147]. We believe that this is partly because keyboard shortcuts need to be learned as well as remembered and have to be carried out by precise key presses. Additionally keyboards might not always be available (e.g., for mobile computing). Thus, related work (e.g., [23, 70, 189]) started to investigate tangible or graspable devices for peripheral interaction. This thesis builds on that and further explores peripheral interaction by adding touch and freehand interaction to the design space of peripheral interaction.

1.1.3 Defining Peripheral Interaction

Peripheral interaction is defined by the interplay between several tasks similar to multitasking. However tasks are not equal in this case but there is at least one small side task (e.g., changing the instant messaging state) or supportive tasks (e.g., changing the size of the brush while drawing in a graphics editing program) quasi-parallel to a larger main task (e.g., reading, writing, drawing). Tasks and therefore interaction can be motivated externally (e.g., through an alert message) or internally (e.g., wanting to change the music). Considering this thesis, tasks can be described as the actions that need to be carried out to achieve a certain (sub)goal.

Research in the field of multitasking, thus also dealing with several concurrent tasks, usually focuses on interruption management, hence external interruptions (i.e., finding the best possible moment for notifying a user of a secondary task [172]). In contrast peripheral interaction can be applied to both, external and internal interruptions aiming at a reduction of cognitive and visual load and hence the effect of interruptions by embedding peripheral interaction into the users daily routines.

To do so, peripheral interaction follows in the steps of calm technology [249, 250] and targets a casual and coarse interaction style in the periphery of the human attention to directly access functionality. Ambient information systems introduced the idea of presenting information to the user in the periphery of attention [197], but in contrast to just perceiving or monitoring information, peripheral interaction transfers this idea from *information* in the periphery to (occasional) *interaction* in the attentional and visual periphery. However, in the spirit of calm technology [249, 250], devices designed for peripheral interaction might move between the center and the periphery depending on the current context and importance of a task as well as the users' needs and motivations.

Fundamental for peripheral interaction are human capabilities such as divided attention (i.e., processing two tasks in parallel without switching channels [255]), automatic and habitual processes (i.e., carried out with little mental effort and hardly any conscious control [21]), and proprioception (i.e., being aware of one's own body, its posture and orientation [35]).

1.2 Research Objectives

Peripheral interaction is a new research field with the first publication, which coined the term, only dating back to 2008 [69]. Inspiration for peripheral interaction thus is nourished by related fields such as ambient information, which already makes use of the periphery of attention but only for the perception of information and not for interaction. Moreover eyes-free interaction [188], explores interaction that consumes no or only minimal visual attention. However, eyes-free interaction does not address the amount of mental attention that is needed for a task being performed. Microinteractions in contrast describe "short-time manual motor interruptions" [262], which should be at best carried out "almost thought free" [13].

In 2008 there existed only one prototype – Darren Edge's Task Management System [69] – which was a token based system (cf., Chapter 4.4.1). Research that was published in the following years targeted different use cases such as home appliances [189] and teachers [22, 23, 25] but still only relied on graspable or tangible devices for interaction. Thus the design space of possible manifestations of peripheral interaction devices by far is not exhausted, raising questions about other suitable interaction styles. For graspable devices as well as devices relying on other input forms many questions on how to build such a system have not been addressed yet (e.g., feedback types). Finally, peripheral interaction does not yet have an established design process or evaluation methodology.

1.2.1 Research Questions

In this open field of peripheral interaction we especially addressed two research questions in this thesis:

> **Research Question 1: How can the design space for (manual) peripheral interaction be extended beyond graspable or tangible interaction?**
>
> **Research Question 2: How can the design process for peripheral interaction be enriched, and which evaluation methodologies can be successfully applied to peripheral interaction?**

Both research questions have been intertwined throughout all projects of this thesis, as we learned during the development of different prototypes (all located around desks equipped with a regular computer), which design approaches successfully worked and which studies helped us to address which design question. Therefore in this theses we conduct research through design to gather meaningful findings for future peripheral interaction devices.

1.2.2 Research Approach

Both research questions have been addressed iteratively by different projects.

Research Question 1: To answer research question 1 we first performed a literature review covering three aspects: (1) background on psychological and physical human capabilities to gain a deeper understanding of our mental and bodily abilities that can be used to achieve interaction in the periphery; (2) three different (manual) interaction styles – graspable (and tangible) interaction, touch interaction and freehand interaction – that are all well established in human-computer interaction; and (3) systems developed in related fields that

make use of both, human capabilities that relate to peripheral interaction as well as one of the three interaction styles.
Based on this literature review we classified the design space for peripheral interaction along six axes – explicitness, input, proximity, granularity, privacy and feedback – and introduced a task-based perspective on peripheral interaction.
As the research field of peripheral interaction is very new and thus not many aspects are yet covered one thesis cannot offer an exhaustive view on peripheral interaction. Consequently we decided on an approach based on probes into the design space. Hence, we are offering several prototypes all investigating one or more of the three manual interaction styles – graspable, touch and freehand interaction. This approach does not cover comprehensive insights for any of the interaction styles but offers a general impression on their suitability for peripheral interaction and reports advantages and disadvantages of each interaction style.

Research Question 2: As previously stated, answering research question 2, was a process, which encompassed all prototypes that we developed as well as some dedicated studies directly targeting the evaluation of peripheral interaction. Generally, measuring what is in the periphery is a complex task, as the periphery is a very intangible concept (cf., Chapter 2.1.4). We are often not aware of our periphery and what we perceive and do in the periphery of attention. During the development of all projects we carried out a multitude of studies relying on early paper-based prototypes, lab experiments with high-fidelity working prototypes as well as in-situ deployments, thus in the everyday environment of the users, which lasted for several weeks. We assessed which evaluation type is suitable for which design question and we were also able to show that lab experiments and in-situ deployments do yield comparable results for aspects that could be tested by both evaluation strategies, thus strengthening the results as well as the study methodologies themselves.
Moreover we developed a designated lab evaluation methodology for desk- and computer-based scenarios. Finally we used this method to evaluate everyday peripheral tasks such as eating, switching on the light or watching TV, to offer a comparison between digital and physical tasks.

1.2.3 Contributions

Based on the previous mentioned research questions this thesis offers three main contributions to the field of peripheral interaction.

Classification: We offer a structured classification along six axes – explicitness, input, proximity, granularity, privacy and feedback. It can be used to classify a project but also points out alternative strategies for each axis, which can be taken into account when designing for peripheral interaction. Moreover we propose a task-based perspective on peripheral interaction, which addresses the use case and its relation to the primary task (cf., Chapter 5).

Design Implications: In the course of this thesis we built six working prototypes incorporating each interaction style in at least three projects. Two basic explorations investigating the general feasibility of peripheral interaction incorporate only one interaction style – StaTube being a graspable device and the Appointment Projection using freehand interaction (cf., Chapter 6). We followed up with two comparative prototypes – the Peripheral Music Controller and Interaction Styles & Feedback – that incorporate all three investigated interaction styles (cf., Chapter 7) and finally the Unadorned Desk 2D and 3D, which investigate touch and freehand interaction relying on spatial memory (cf., Chapter 8). From these six probes into the design space we derived implications intended to guide future projects incorporating peripheral interaction by targeting benefits, learnability and habituation, visual and mental attention, interaction styles, feedback and handedness (cf., Chapter 10).

Evaluation Strategies: All projects were evaluated either through a lab experiment or through an in-situ deployment or even both. For early testing, especially to find suitable mappings for different peripheral interaction styles and use cases we successfully used paper-based prototypes. We further developed a lab study methodology for desk- and computer-based primary tasks. Moreover we carried out in-situ deployments for several weeks. For all three evaluation methodologies we state, which design questions could be answered by which approach (cf., Chapter 9).

1.3 Thesis Overview

This thesis is structured in three parts, which are also depicted in Figure 1.1.

Introduction: In **Chapter 1** we introduce the topic and motivate the research approach by listing the research questions and the contributions of this thesis.

Part I: Anchoring Peripheral Interaction: In the first part we review related work relevant for peripheral interaction. In **Chapter 2** we introduce background on human attention including divided attention, multitasking and interruptions as well as habituation and automatism. Finally we review the term periphery and define our understanding of the periphery in this thesis. Moreover we discuss background on haptic perception including proprioception, spatial memory and spatial interaction as well as ambidexterity. In **Chapter 3** we offer a short introduction to the three interaction styles that will be applied to peripheral interaction in the upcoming thesis – graspable (and tangible) interaction, touch as well as freehand interaction. We show example applications for each interaction style and state why we consider this interaction style to be suitable for peripheral interaction. In **Chapter 4** we review systems that make use of the before mentioned human capabilities and combine them with one (or more) of the three interaction styles. Again we show example applications for each of these research fields.

Chapter 1: Introduction
Motivation, Definition of Peripheral Interaction, Research Objectives, Contributions

Part I: Anchoring Peripheral Interaction

Chapter 2: Capabilities
Human Attention: Divided Attention, Multitasking and Interruption, Habituation and Automatism, The Periphery
Haptic Perception: Proprioception, Spatial Memory and Spatial Interaction, Ambidexterity

Chapter 3: Interaction
Graspable and Tangible: Background, Example Applications, Link to Peripheral Interaction
Touch: Background, Example Applications, Link to Peripheral Interaction
Freehand: Background, Example Applications, Link to Peripheral Interaction

Chapter 4: Systems
Eyes-Free Interaction, Microinteractions, Ambient Information, Peripheral Interaction
Background, Example Applications, Linking Capabilities and Interaction

Part II: Prototyping Peripheral Interaction

Chapter 5: Classification and Perspective
Design Space, Task-Based Perspective

Chapter 6: Basic Explorations
StaTube: Graspable Interaction, In-Situ Deployment
Appointment Projections: Freehand Interaction, Lab Experiment, In-Situ Deployment

Chapter 7: Comparison of Interaction Styles
Peripheral Music Controller: Graspable, Touch, Freehand Interaction, In-Situ Deployment
Interaction Styles & Feedback: Graspable, Touch, Freehand Interaction, Lab Experiment

Chapter 8: Exploiting Spatial Memory
Unadorned Desk 2D: Touch Interaction, Lab Experiment
Unadorned Desk 3D: Freehand Interaction, Lab Experiment

Chapter 9: Evaluating Peripheral Interaction
Design Process, Controlled Lab Experiment, Case Study Comparing In-Situ Deployment and Lab Experiments, Everyday Tasks

Part III: Reflecting on Peripheral Interaction

Chapter 10: Design Implications for Peripheral Interaction
Benefits, Learnability and Habituation, Visual and Mental Attention, Interaction Styles, Feedback, Handedness, Evaluation

Chapter 11: Roundup & Future Work
Summary of Results, Limitations, Future Work

Figure 1.1: Structure of this thesis. Chapters visualized in parallel depict different aspects, which are later revisited and connected by subsequent chapters.

Part II: Prototyping Peripheral Interaction: In the second part we explore the design space of peripheral interaction. In **Chapter 5** we theoretically assess peripheral interaction and offer a classification and a task-based perspective. The following three chapters each depict two projects. In **Chapter 6** we introduce two basic prototypes, which investigate one interaction style each. *StaTube* is a graspable device, which can be used to modify one's instant messaging state while the *Appointment Projection* offers direct access to upcoming appointments through freehand interaction. Both prototypes have been assessed through in-situ deployments. Additionally the Appointment Projection was also evaluated in the lab. In **Chapter 7** we describe two projects, which both compare all three interaction styles, graspable, touch and freehand interaction. The *Peripheral Music Controller* was deployed in an eight-week in-situ study while *Interaction Styles & Feedback* was tested in the lab also exploring visual feedback. In **Chapter 8** we offer two manifestations of the *Unadorned Desk*, which both make use of spatial memory and spatial interaction. The Unadorned Desk 2D combines discrete touch input with spatial memory while the Unadorned Desk 3D makes use of freehand gestures in combination with spatial interaction. Both manifestations have been evaluated in the lab. Thus, the second part offers probes into the design space of peripheral interaction especially related to the different interaction styles. Finally we discuss the design process and especially evaluation strategies for peripheral interaction in **Chapter 9**. We propose a lab-based evaluation methodology and discuss, which design questions can be addressed by which study type. Moreover we compare peripheral everyday tasks to peripheral digital task.

Part III: Reflecting on Peripheral Interaction: In the third part we summarize in **Chapter 10** the implications for peripheral interaction based on all previous prototypes and experiments, which shall help to guide future research in peripheral interaction. In the final **Chapter 11** we sum up the main contributions of this thesis, state limitations of this work and give an outlook for future research in the field of peripheral interaction.

I

Anchoring Peripheral Interaction

Chapter 2

Capabilities: Human Attention and Haptic Perception

Synopsis

The theory of divided attention assumes that human attention can be split up into mental resources, which can be allocated to different tasks in parallel. However, several factors influence the division of mental resources, among them task difficulty, familiarity and motivation. Additionally interferences can occur such as a task requires more attentional resources than available or two tasks access the same modality (or analyzer). The Multiple Resource Theory tries to predict, which tasks might interfere. This capability of dividing attention forms the basis for multitasking. Through external but also internal interruptions tasks are interleaved, causing effects such as the interruption and resumption lag. Minimizing (the duration of) these interruptions, leads to less errors in the primary task. Through habituation, tasks that are well trained and known can be performed with just minimal distraction and interruption, often quasi parallel to the primary task (i.e., in the periphery, thus outside of the main focus of attention).
Apart from attentional capabilities, haptic perception plays an important role for manual peripheral interaction, which is the focus of this thesis. Important properties are proprioception (being aware of the own body posture), spatial memory (recalling spatial layouts) and ambidexterity (being able to interact with both hands). These two aspects – human attention and haptic perception – form the basis to carry out tasks in the periphery.

In Weiser's and Brown's vision of ubiquitous computing [249, 250] one term is very central – *calm technology*. In their own words "calm technology engages both the center and the periphery of our attention, and in fact moves back and forth between the two" [249]. As one manifestation of calm technology, Weiser and Brown introduce the Dangling String, created by Jeremijenko. The Dangling String visualizes network traffic by whirling a string dependent on the number of bits running through an Ethernet cable. Office workers can therefore – without focusing their attention on it – determine how much network traffic is currently generated and hence how busy the office is. This first example of ambient information [197], already emphasizes the interplay of the center and periphery of the attention for the perception of information.

This Chapter gives an overview of human attention, which we consider the most relevant aspect of cognition in terms of peripheral interaction. Further we look into fundamental human capabilities as peripheral interaction in contrast to ambient information not only aims at perception but also at *active interaction* in the periphery.

2.1 Human Attention

One of the earliest references relating to attention dates back to William James in 1890 [134] stating: "Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreutheit in German." In other words, William James considers attention as one indivisible state of mind, which can only be directed at one single object. Early attention theories built on this single-channel behavior [255], i.e., assuming there is only one channel, which can execute a task. Hence, the execution of two tasks in parallel takes at least as long as the sequential execution of the same two tasks. However, subsequent researchers acknowledged that humans engage in multiple activities [176] and are – to some extent – able to divide their attention among these activities [141]. Wickens and McCarley [255] even point out five types of attention – focused, selective, switched, divided, and sustained.

This Chapter examines the concept of *divided attention* in more detail, as it is the basis for ambient information as well as peripheral interaction, where attention is divided between one focal (primary) task and (at least) one peripheral (secondary) task. Further this Chapter addresses *multitasking* and *interruptions* alongside *habituated* tasks. Finally the term *periphery* will be defined for this thesis.

2.1.1 Divided Attention

The theory of divided attention is introduced by Daniel Kahnemann [141] and relies on the idea of *mental resources*, which are limited and can be distributed among different tasks. Tasks differ in the amount of mental resources required, i.e., tasks that are considered to be difficult acquire more resources, whereas simpler tasks only acquire a little amount of resources. For example solving a complex mathematical problem requires more mental resources than having a casual chat with a friend. Difficulty however is not the only parameter influencing the number of mental resources needed to perform a certain task. Familiarity with a task (discussed in more detail in Chapter 2.1.3) as well as internal factors such as effort and motivation dedicated to a task and external factors such as stimuli from the surrounding environment influence the number of mental resources allocated to a task [90].

We all observe parallel execution of tasks in our daily life, e.g., going out for dinner and eating a meal while listening to a friend recounting their experience during their last holidays. However, we all are well aware that not all tasks can be easily performed in parallel (e.g., reading a text while following the explanations of a colleague) although mental resources are still available (e.g., it would be easily possible to take a sip of coffee and keep on reading). To acknowledge this observation Treisman [230] introduces analyzers. While one *analyzer* follows strict serial processing, several analyzers can be executed in parallel. Applied to our example that means that reading a text and grasping for a cup of coffee and drinking addresses different analyzers, while reading a text and listening to a colleague address the same analyzer (here: the speech center). Based on this model there is only one analyzer for each feature. However, Treisman extended the model to a "common pool of capacity" [231], which includes control processes. Hence, this model shows that it is difficult – often even hardly possible – to divide attention within one modality, but there is no guarantee that division among separate modalities is certainly successful [141]. Additionally one should note that it is hard to address two demanding tasks at once (even if they require different analyzers/modalities) because attention can be divided more easily at low levels, but is "nearly unitary at high levels of effort" [141].

Thus far the theory of divided attention states that we are able to perceive several stimuli and execute several tasks in parallel, at least to some extent. However, there are still too many stimuli around us to address everyone. Divided attention therefore adopts the idea of a *filter* from the theory of selective attention, which chooses the presumably important stimuli almost unconsciously based on the following four factors [141]: (1) involuntary attention (new signals, unexpected movement, etc.), (2) momentary intentions (e.g., wanting to listen to the news on the radio), (3) evaluation of demands (whenever several actions ask for more resources than overall available, we try to complete one) and (4) effects of arousal (when arousal is high, attention will more likely be allocated to one controlled process, e.g. reading a good book). Figure 2.1 illustrates the theory of divided attention including the filter and several analyzers.

As stated, even with our capability of dividing attention among different tasks, there are certain constraints, which limit the parallel execution of tasks. Kahneman [141] names two

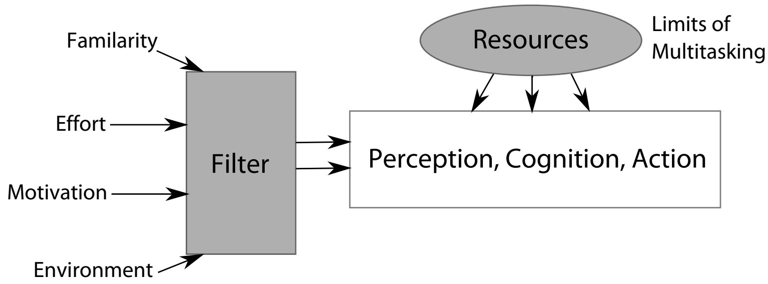

Figure 2.1: A simplified model of attention: the filter sorts stimuli based on properties such as familiarity, effort, motivation and environment. Additionally mental resources might limit the execution of several tasks at once. (Adapted and redrawn based on [255].)

types of interferences: *Capacity interference* occurs when a tasks requires more attentional resources than currently available. A *structural interference* arises because two (or more) tasks want to access the same modalities (or analyzers). However, one should note, that even if we predict an interference we cannot predict which tasks will suffer depletion as we are capable to decide, which task we want to prioritize and hence which task we want to neglect or at least execute with diminished attention.

In summary, the theory of divided attention considers a limited pool of resources, but this limitation is not based on a fixed number but "is variable from moment to moment" [141], for example influenced by effort, motivation and general wellbeing. If a task with very high attentional demands is present, it is less likely that resources can be divided. Generally people are able to attune their attention to a specific task and ignore other tasks and their attentional demands. Hence we are not extradited to the distribution of attentional resources but can actively intervene. The main influence on dual-task performance are task difficulty (i.e., the amount of resources required) and the availability of structures (e.g., visual, auditory).

Multiple Resource Theory

The *Multiple Resource Theory* (MRT) was proposed by Wickens [254] and is designed as extension to the model of divided attention. Wickens states that differences in performance of different parallel tasks cannot only be attributed to difficulty of the tasks or different allocation policies (cf., four factors by Kahneman [141]). Previously Treisman [230] introduced analyzers as a first step to explain why some tasks are easier to be performed in parallel than others, which was picked up by Kahneman as structural interference. MRT further digs into the interference of parallel tasks by analyzing time-sharing of tasks, and attributes differences in performance of parallel tasks to the usage of different structures. In other words, similar to the concept of analyzers, tasks which use similar structures interfere more than tasks using different structures. One simple example for different structures are the two senses – visual and auditory – that in many cases (but not all) are able to be used for two different tasks in parallel (e.g., listening to music while observing the traffic).

The model consists of four dimensions (see Figure 2.2): processing stages, perceptual modalities, visual channels and processing codes [254]. *Processing stages* consist of perception, cognition and responding, whereas perception and cognition are addressing the same structures but responding addresses separate ones. Hence, perceiving and cogitating will interfere if two parallel tasks ask for either one of them. *Perceptual modalities* in MRT consist of the visual and auditory sense. As previously stated, dividing attention between the visual and auditory channel (cross-modal time-sharing) is possible, while sharing either the visual or the auditory channel (intra-modal time-sharing) among different tasks is hardly possible (e.g., listening to the radio and to the TV in parallel can hardly be achieved). However, if visual and auditory tasks are very close together (e.g., reading and listening to somebody speaking) a masking effect is bound to appear. Besides the division between visual and auditory, the *visual channel* is again divided into two channels: the focal and the ambient vision. Even while focusing on one thing (e.g., the computer screen), we are still aware of changes in our surroundings (e.g., a person passing by outside of the window). The fourth dimension – *processing codes* – is divided into spatial and verbal processing. Spatial processes mainly refer to manual interaction (e.g., usually we can talk to somebody while driving a car and thereby holding the steering wheel or shifting gears).

When talking about MRT it is important to note that the model is built to predict if an interference is likely to appear for two different tasks, but by no means can the model predict that two tasks can be executed without an interference (cf., reading and listening to a conversation do address different modalities but still might interfere). Additionally, if the model predicts an interference for two tasks, there is no prediction, which impact this interference might bear, for instance, which task will be neglected [255].

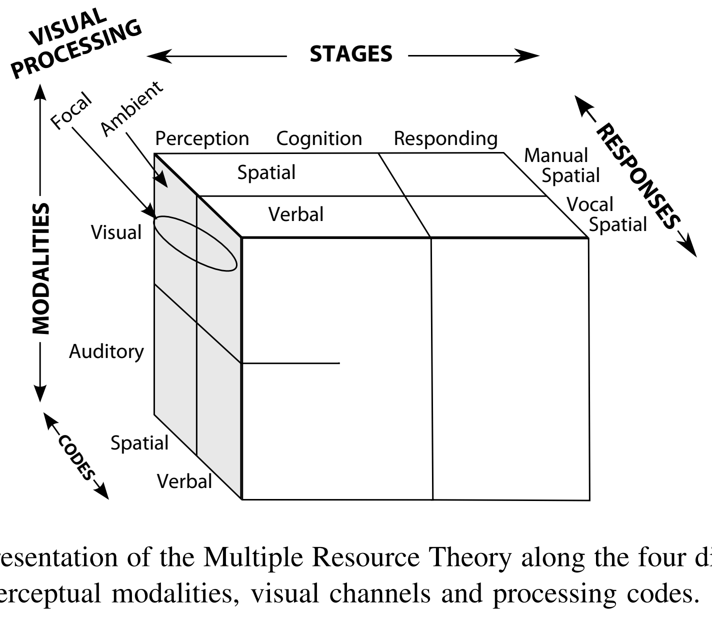

Figure 2.2: Representation of the Multiple Resource Theory along the four dimensions – processing stages, perceptual modalities, visual channels and processing codes. (Redrawn based on [255].)

Visual Attention

Wicken's MRT already hints at the visual channel as one important aspect when dividing attention. The (focal) visual channel works strictly sequential – although very fast – with only about 2° of sharp vision, but we can perceive about 210° peripherally [141].

Kahneman [141] distinguishes between three types of eye movement: *spontaneous looking* (independent of current tasks but invoked by stimuli such as novelty), *task-relevant looking* (acquire information about the current primary task), and *looking accompanied by internal processing*. The latter also provides a clue about people's thoughts. When thinking about something, one usually draws the visual attention towards related objects – even if these objects currently provide no information. The same is true when talking in a group of people about somebody in the group. Usually all eyes are automatically directed towards this person. Similarly when overhearing a conversation, although this is obviously an auditory task, usually one is drawn to also look at the people talking. Hence, there is a connection between visual attention and cognitive attention or in other words, visual attention – even if it would not be necessary to look at a certain object or person – helps to focus ones' thoughts. Consequently, to some extent the eye movement can be used as measurement for cognitive effort [141].

In summary, divided attention is the basis for parallel execution of tasks. However, not only the allocation of mental resources influences multitasking behavior but also perceptual modalities (as depicted by the Multiple Resource Theory) such as the auditory or visual channel. For the upcoming work in this thesis, next to the distribution of mental resources, the utilization of the visual channel will be of importance to assess the success of devices designed for peripheral interaction, as this channel is hardly dividable.

2.1.2 Multitasking and Interruption

Dividing resources between different tasks is the foundation for multitasking. Research on multitasking includes the execution of several tasks in parallel as well as closely interleaved [37]. This span between sequential and parallel task execution was defined as the *Multitasking Continuum* by Salvucci et al. [209]. Figure 2.3 depicts several examples of multitasking ranging from concurrent multitasking (minimal time – only seconds – between task switching) to interleaved multitasking (longer time – minutes or even hours – between task switching).

Multitasking usually is triggered by an interruption – either externally or internally [176]. *External interruptions* are caused by the environment. In the work context external interruptions are often caused by colleagues, stopping by at the desk or calling, or by alerts or notifications such as "a new email has arrived". *Internal interruptions* are intrinsically motivated, hence by a person's own thoughts. Interestingly people who are exposed to many external interruptions also tend to interrupt themselves more often [61]. Jin et al. [135] collected seven types of self-interruption: adjustment (changing something to improve overall

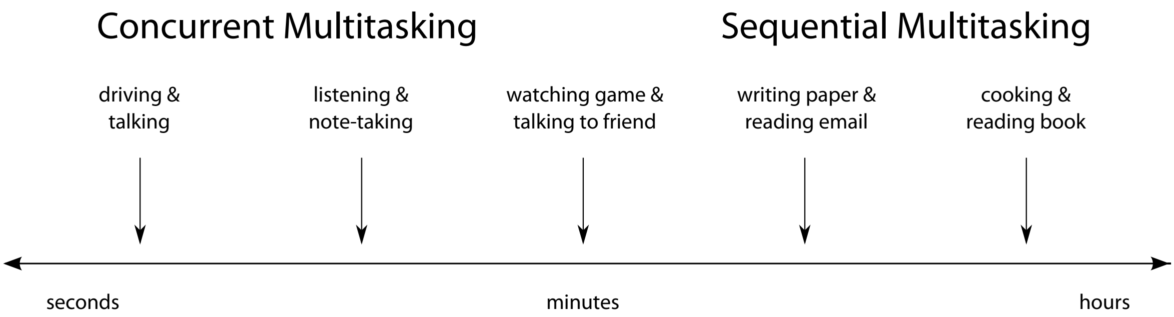

Figure 2.3: The Multitasking Continuum ranging from concurrent multitasking with only seconds between task switches to sequential multitasking, which might include task switches after hours. (Redrawn based on [209].)

performance), break (turn towards a preferred task), inquiry (acquire additional information), recollection (remembering another task that needs to be done), routine (addressing a task out of routine), trigger (something in the primary task stimulated another task) and wait (bridge waiting time in the primary task). All of these self-interruptions have positive consequences such as improving productivity, resting and inspiring new ideas but also negative consequences such as procrastination and hence delaying the primary task. In a study, these self-interruptions caused delays of up to 4 minutes.

A recent study [9] showed that even rather *short interruptions* (independent whether internally or externally interrupted), which took on average 4.4 seconds, tripled the number of errors, while an interruption of on average 2.8 seconds already doubled the number of sequence errors (i.e., repeating already executed steps or generally confusing task execution order). Altmann et al. [9] showed that this was mainly due to the imposed focus switch. This reinforces our goal of reducing focus switches with the help of peripheral interaction. However, other errors (not related to the expected sequence of task execution) were not affected by these short interruptions. But not only the duration of the interruption by the secondary task, but also the task itself influences the resumption and execution of the primary task. In a very extreme example Monk et al. [178] compared staring at a blank screen to the execution of a tracking task in between the primary task. The resumption lag was significantly shorter during the "blank screen" condition, assuming that this time was used to remember and recall the primary task. Additionally, if an interrupting task is related to the current primary task, the resumption lag is also shortened [57].

Related work states different numbers in terms of *interruption frequency* ranging from 3 [85] to 12 minutes [135] with half of all interruptions being internal interruptions [135]. From these numbers it is obvious that interruptions occur frequently and people have to deal with them multiple times a day. Switching between tasks causes effects such as a delay between both tasks (the interruption and resumption lag) [8], duplicated work (i.e., restarting at the beginning of a subtask) [255] and increased execution time (between 3% and 27%) [17] and twice as many errors in the interrupted task [17]. Additionally stress, annoyance and frustration are problems caused by multitasking [17, 163].

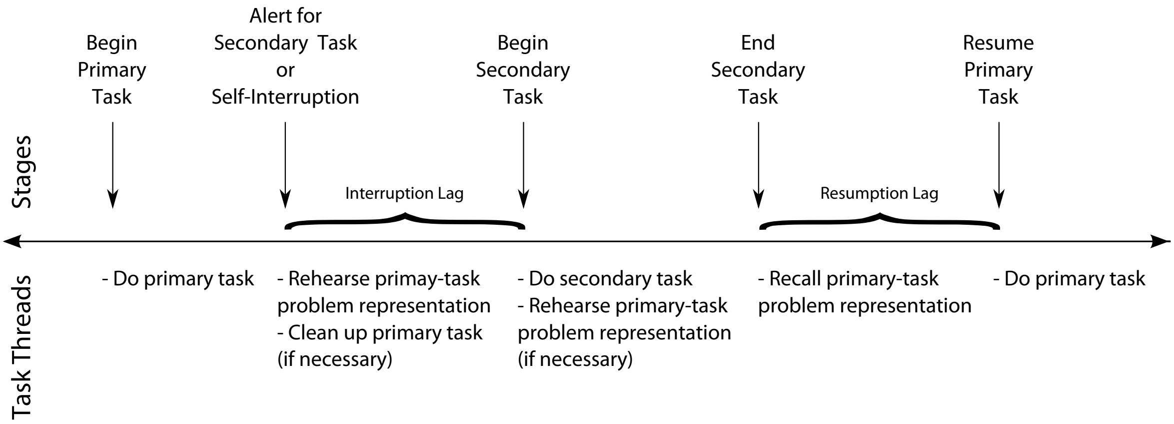

Figure 2.4: Procedure of sequential multitasking including interruption and resumption lag. (Adapted and redrawn based on [209])

Figure 2.4 gives an overview of a typical multitasking sequence and its phases. The interruption lag (also called preparation phase [126]) and resumption lag are one effect of multitasking. The *interruption lag* [8] is the time between the interruption (internal or external) of the current primary task until starting to work on the secondary task. This time is used to convey the primary task into a save state and remember that state for later resumption (often even subconsciously [126]). Consequently it is not necessarily bad if the interruption lag takes a bit of time, as resumption can be speeded up if the state of the primary task is easily recalled. During the interruption lag attentional resources tied to the primary tasks are freed and can be used by the secondary task. The *resumption lag* [8] is the time between ending the secondary task and restarting the suspended primary task. For rather small tasks – as in this thesis – usually the secondary task is completed upon resuming the primary task and hence no state has to be saved for later recollection of the secondary task. However, the previous state of the primary task has to be recalled. Recall of the primary task usually is faster if the primary task was left at a stable state. Interruption lag as well as resumption lag can be positively influenced if the interruption happens at subtask boundaries, where mental demand is temporary diminished [16]. This not only leads to shorter interruption and resumption lags and hence shorter task execution time, it also decreases annoyance [17].

To sum up, interruptions are always less harmful if they occur during times with low mental demands. For internal interruptions people usually automatically select such moments for interrupting themselves [37]. For external interruptions statistical models relying on sensor data are developed with prediction accuracies between 75% and 82% [79, 124]. However, other factors also affect task switching including "task priorities, hierarchical task structure, stress factors, alert type, task length and complexity, and similarity between tasks" [37].

2.1.3 Habituation and Automatism

In this Chapter we up to now learned that parallel execution is fostered by simple tasks. Simple here not only refers to the objective difficulty of a task but also to the level of skill. In other words, tasks that are highly trained – such as walking or typing – can be executed in parallel by skilled people although the tasks themselves would not be considered easy. These tasks are also called *automated* or *habitual* tasks.

Habitual tasks are already recognized by James [134] in the late 19^{th} century and are characterized as requiring little or no attention [255] or effort [212], they can be executed fast and in parallel, are not easily disturbed by stress [212] and are evoked unconsciously [1]. Miyata and Norman [176] state four situations, which compulsively lead to conscious control: new tasks or tasks that are not well learned, critical tasks that are difficult or risky, whenever an automatic reaction is supposed to be overwritten, or if interrupted by a different activity. As already indicated by this list, once a behavior is automatic it is hard to control it or refrain from executing it when triggered [212].

Apparently tasks that are not considered to be trivial can become habitual and be carried out without thinking about them (cf., typing or walking). However, especially these non-trivial tasks need intensive training before they are carried out unconsciously [1, 212]. Hence, training leads to a reduction of necessary mental resources. As both examples – typing and walking – already illustrate, habituation is especially powerful for motor tasks [255].

Habitual or automatic tasks not only require less mental resources, but studies proved that these tasks are usually executed with very high accuracy and only few errors occur [9]. Additionally they are considered as unconscious processes, hence, habitual processes are usually not triggered by sophisticated considerations but by a certain goal, which previously was satisfied by the evoked process [1]. Reducing considerations and thus mental load is one goal of peripheral interaction, thus we believe that habituation is an important aspect of successfully applied peripheral interaction.

However, habituation is not the only factor for successful parallelism during multitasking. Wickens and McCarley [255] further list single-task skill level (although the task is not automated, less mental resources are needed) and task-specific as well as general time-sharing skills (e.g., previously discussed strategies of leaving a primary task in a stable state before attending the secondary task). Additionally, even highly trained tasks can fail to be carried out in parallel: when asked something very complex while walking – for instance mental arithmetic – most people tend to stop walking (which is usually highly trained and automated) and continue again after solving the problem [141].

2.1.4 The Periphery

We summarized learnings about divided attention, multitasking and habituation, which show that we are – to some extent – able to perform several tasks in parallel. Peripheral interaction

Foreground/Background

Human - Human	conversation, telephone, video conf.	"Portholes"
Human - Computer	GUIs	smart house technology

Figure 2.5: Buxton's Model on Foreground/Background Interaction (Redrawn based on [41])

also aims at divided attention and thus multitasking but with the specific goal of moving tasks to the periphery of attention (visual and cognitive). Mark Weiser states "that only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals" [248].

One of the first models dealing with the periphery in Human-Computer Interaction (HCI) is proposed by Bill Buxton [41]. Buxton already states that "a significant amount of the complexity in humans dealing with technology is due to having to explicitly maintain state (or context) as a foreground activity" [41]. His model (see Figure 2.5) consists of a matrix, which divides interaction into foreground and background (which refers to the periphery) and into human-human (but technology mediated such as using a telephone) and human-computer interaction (such as typing in a text processing application). As Buxton already states in 1995, most of the interaction with computational devices is located in the left – the foreground – column, and this holds true until today. However, Buxton's definition of background activities is slightly different from the one proposed in this thesis. As one potential background activity for technology-mediated human to human interaction he states a tool, which monitors the availability of contacts for videoconferencing and notifies the user if a desired contact becomes available. However, setting the system to the desired contact is still a foreground activity (Portholes). On the other hand, as human-computer interaction in the periphery he considers a smart house, which for example switches on the light when entering a room, which is an example for implicit interaction, thus interaction, which is understood as input by the system but not consciously carried out to interact with the system [211]. Peripheral interaction according to our definition in contrast addresses *explicit* interaction by the user, which still resides in the periphery.

Miyata and Norman [176] categorize tasks into three groups: *foreground activities*, *background activities* and *suspended task*. The foreground activity is in the focus of the user and suspended tasks in contrast are not currently addressed at all. Background activities however can be divided into two sub types – external and internal background activities. An example for an external background activity would be Buxton's example of video conferencing where an application can be set to monitor the state of contacts. Internal background activities on the other hand are "ongoing activities under 'automatic' or subconscious control" [176], which is in line with our definition of a peripheral task.

A task being peripheral does not imply that it is unimportant [249]. It merely indicates that it can be perceived or performed with minimal attentional resources and (quasi) parallel to other activities. It is important to notice that not only offering interaction in the periphery but – as Buxton states – "to make transitions seamlessly from quadrant to quadrant" [41] is a design goal for peripheral interaction. As Bakker et al. [22] state in their analysis of real life peripheral tasks, some activities (such as ironing) can be divided into different sub tasks with some of them being foreground activities (such as folding clothes) while others can be performed in the background (such as moving the iron over the clothes). Tasks executed in parallel (such as watching TV) can meanwhile also move between the center and the periphery. Thus the periphery can enrich interaction without overburdening us [249].

Based on the related work mentioned before, for the remainder of this thesis the periphery is defined as everything that is not the visual or cognitive focus. The focus is defined as the task where most attentional resources (visual and cognitive) reside (see Figure 2.6). In contrast – no matter if attentional resources are allocated to it or not – every other task is considered to be in the periphery. Tasks thereby can fluently move between the center and the periphery but to be considered as peripheral tasks, the tasks should be performable in the periphery for most of the time. This can also be based on a sub task level.

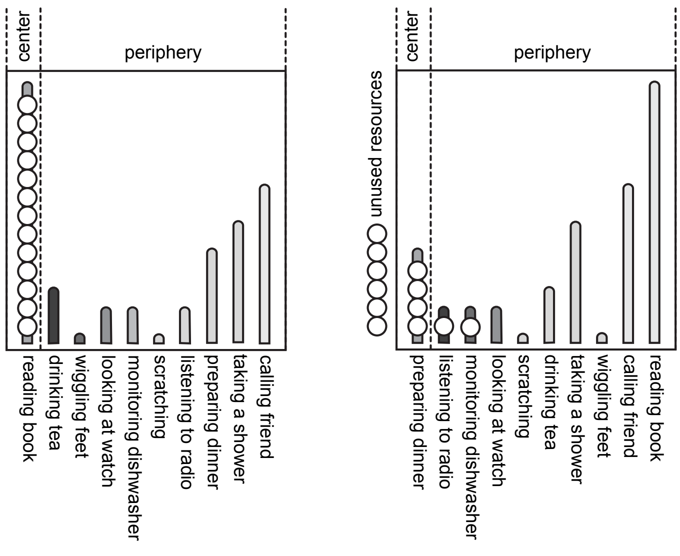

Figure 2.6: Illustration by Bakker et al. [21] depicting resource allocation among tasks. Left: reading – a high attentional task – taking all resources; Right: preparing dinner – a low attentional task – with spare resources distributed to other (or no) tasks.

2.2 Haptic Perception

Previously we assessed our attentional capabilities and also looked into the visual sense in terms of visual attention. However, when interacting with the physical world we not only rely on vision but on all our five senses: visual, auditory, haptic, smell and taste. Though, for interaction with digital devices we are mainly limited to our visual, auditory and haptic senses. This work is inspired by peripheral interactions in the physical world, which we mostly carry out with the help of the hands and arms [22]. Hence the haptic perception is of particular importance when transforming peripheral interaction from the physical to the digital world.

As terms are not clearly defined in this context, we use a definition in line with the classification by Richter [205]. Richter divides haptic perception in three categories: interoception (feeling of internal organs, hunger and pain), proprioception (orientation and movement of the body) and exteroception (tactile perception of surfaces, temperature and pain on the skin). The sense of touch is based on both, proprioception and exteroception. Moreover, spatial memory (to recall spatial locations) and generally the use of both arms in parallel (ambidexterity) form the basis for manual peripheral interaction, as discussed in this thesis.

2.2.1 Proprioception and Exteroception

While the sense of touch gives us important feedback when reaching for something, proprioception is especially important when talking about interaction. The term proprioception is often mixed up with the term kinesthesis. In line with Hopkins [119], we here only refer to the related haptic properties as proprioception. Proprioception tells us how our body and limbs are positioned and oriented [36]. One classical example of proprioception is our ability to touch the tip of our nose even with closed eyes. Hence, we are well aware of our body posture without relying on our visual channel [229]. Apart from that, due to proprioception we are able to estimate the weight of items that we are holding in our hand. Further without proprioception it is very hard to keep balance (the sense of balance located in our inner ear is part of proprioception), even when we have visual feedback about our body posture [148].

Mine et al. [175] found that feedback based on proprioception enriches interaction (e.g., in terms of precision) compared to only visual feedback (e.g., when navigating in virtual worlds). They name three potential advantages of interaction based on proprioception: *direct manipulation* (locating artifacts close at hand), *physical mnemonics* (locating controls relative to or actually on the body), and *gestural actions*.

Concerning manual peripheral interaction – the focus of this thesis – exteroception supports graspable and touch interaction, especially in terms of interaction with minimal visual attention. However, exteroception is missing for freehand interaction in midair, thus freehand interaction solely relies on proprioception in terms of inherent haptic feedback [253].

2.2.2 Spatial Memory and Spatial Interaction

Spatial memory or spatial mental models [233] describe our ability to memorize and recall the spatial layout of locations (ranging from large scale areas such as familiar cities to the spatial layout of the own desk or the layout of application icons on a computer desktop or mobile device [94]). Capabilities based on the previously explored proprioception (cf., Chapter 2.2.1) coupled with spatial memory lead to so called spatial interaction [115], which uses the body as a spatial reference frame. Nevertheless, not only the body itself but also physical artifacts can be used as spatial reference frame (e.g., objects located on the desk when retrieving another item on the desk) [115]. However, while spatial memory works well for addressing relative locations of objects [115], spatial memory cannot be used for precise judgment of distances [233].

Several applications in the scope of Human-Computer Interaction (HCI) make use of spatial memory. For example Data Mountain [207] allows spatially arranged placement of objects in 2D. In a study (based on web browser favorites) Robertson et al. found that retrieval of items was faster and less error-prone with the spatially arranged layout compared to standard linear interfaces. Gustafson et al. [93] take it one step further and give up on a visual representation altogether and developed Imaginary Interfaces. By forming an "L" with their non-dominant hand in mid-air users create their spatial reference frame for interaction. Interaction with their dominant hand is considered as input in reference to the "L". They not only base this interaction on spatial memory but also on short term visual memories (cf., visuospatial sketchpad [15]). This interaction style not only makes room for miniaturization but also for parallel input. While for example a mobile phone is already used for talking to somebody, one could still interact with the device (e.g., to add an appointment to the calendar), however, in contrast to the aspired goals for peripheral interaction, here users still have to interact with focused visual attention.

2.2.3 Ambidexterity

Spatial interaction usually relies on ambidexterity [115]. Based on the observation that we extensively use bimanual interaction in everyday life, the field of bimanual interaction in HCI is already explored since the eighties and several studies showed that bimanual interaction (for compound tasks) outperforms one-handed interaction in many cases [44, 151] because it offers a kinesthetic or spatial reference frame [27]. (In comparison, in case of one-handed interaction the dominant hand usually outperforms the non-dominant hand [193]).

Guiard's kinematic chain [91] offers a theoretical framework for bimanual (and asymmetric) interaction. Guiard considers each hand as motor (ignoring internal attributes), which moves in space to accomplish tasks. Tasks can be symmetric or asymmetric [91]. *Symmetric tasks* describe tasks in which both hands carry out the same movement (e.g., weight lifting). However, the majority of tasks are *asymmetric*, which are tasks in which both hands are involved but carry out different movements (e.g., playing the guitar). The last category – unimanual tasks – can be seen as a subclass of asymmetric tasks with one hand being unoccupied (e.g., brushing teeth). This categorization is especially reasonable as there is no proof that a seemingly unoccupied hand does not affect the performance of a task.

There are many tasks, in which it is hard to name one hand being dominant over another (cf., playing the guitar) and we usually have two possibilities to assign our hands to a bimanual task (e.g., when dealing cards). However, the non-dominant hand (to simplify this theory Guiard only considers the right hand to be the dominant hand) usually acts as the reference frame for the dominant hand [91]. Even with the left hand not moving it offers stabilization. Writing speed decreases up to 20% if one is not allowed to use the left hand but uses for example a clamp instead to hold the paper. This is because the left hand – while seemingly hardly in motion – orients the paper according to the needs of the right hand, hence, the left hand offers a stable state for the right hand. Guiard calls this the *Right-to-Left Spatial Reference*. This effect is further strengthened by the observation that the right hand (the dominant hand) can interact more precisely (concerning accuracy and time) than the left hand. Guiard sees a mapping of tasks in this and speaks of the macrometric and the micrometric hand. This property is called *Left-Right Contrast in the Spatial-Temporal Scale of Motion*. The last principle named by Guiard – *Left-Hand Precedence in Action* – follows the other two as it states that the left hand usually starts the interaction and stabilizes the object for the (precise) interaction with the right hand. These three principles form the basis for the kinematic chain, which states that the two motors – our two hands – are "assembled in series" [91].

In the context of peripheral interaction bimanual interaction can be a means of carrying out two tasks in parallel with the help of both hands individually. However, Kabbash et al. [140] already state that bimanual interaction could increase cognitive load, which is not in line with the characteristics of peripheral interaction, which aims at an interaction style in the periphery of the attention. However, in subsequent studies they found that – if designed well – two-handed interaction can be carried out without increasing attentional load even with little or no training of the interaction style [140], which is attributed to the advantages of the spatial reference [151]. Still, the dominant hand seems to demand more attentional resources, as it usually performs the more precise activity [193]. Additionally visual attention can be reduced because of the reference frame offered by the hands, which supports eyes-free interaction [116]. However, if both – visual and spatial feedback are provided – visual feedback is the dominant feedback channel [27].

In summary, our physical and haptic capabilities such as proprioception, spatial memory and ambidexterity can be applied to support interaction without visual attention and thus in the visual periphery. We believe that if successfully paired with our attentional capabilities, interaction in the background or periphery of our attention can be achieved.

Chapter 3

Interaction: Manual Interaction Styles

Synopsis

When interacting with digital devices with our hands, several interaction styles apart from the traditional input, with keyboard and mouse, can be imagined. The three most prominent examples are graspable/tangible interaction, touch and freehand interaction. Graspable and tangible interaction describes interaction with physical artifacts, which are coupled with virtual data. These physical artifacts offer direct access to data, shortening interaction sequences, and make use of our spatial and motor memory, which supports peripheral interaction. Touch input can be direct or remote, single- or multi-touch and discrete or continuous. Especially continuous input, not mapped to one distinct location (e.g., a button) on the touch sensitive area, offers eyes-free interaction, which reduces visual attention and hence fits well into peripheral interaction. Last but not least, freehand interaction is based on midair gestures similar to gestures while talking to emphasize our spoken words or even replace them. Freehand gestures also rely on proprioception and spatial memory supporting peripheral interaction. Negative effects of freehand gestures, such as fatigue, are not very likely to arise, as peripheral interaction aims at short episodic interactions. While this chapter gives a short (historic) introduction about these three interaction styles, the suitability of them for peripheral interaction will be assessed in detail in Part II.

In the beginning of the eighties the graphical user interface (GUI) was introduced by Xerox Parc with their Xerox Star and soon after that by Apple and their Apple Lisa [201]. Interaction with personal computers was carried out with the help of a keyboard and mouse, which is still the dominant way of interaction today after 30 years. However, even before and of course also since the introduction of the graphical user interface researchers investigated different forms of input, often inspired by interaction with physical objects in our daily life.

This chapter gives a brief overview on the evolution of graspable and tangible interaction as well as touch and freehand interaction, which we will investigate in more detail in the remainder of this thesis in terms of applicability for peripheral interaction.

3.1 Graspable and Tangible Interaction

Graspable interaction or **graspable user interfaces** were introduced by Fitzmaurice [78] in 1995. He developed them by investigating interaction with physical artifacts such as Lego bricks, which showed that people interact with high parallelization in terms of bimanual interaction (cf., Chapter 2.2.3) including crossing arms during interaction. Many different interaction styles such as picking up or sliding items were observed showing a rich design space for graspable interaction. The goal of graspable interaction is to make manipulation of digital information more direct by closely coupling "physical handles" with "virtual objects" or content and thereby blending the "the physical and virtual world" [78]. Graspable artifacts have distinct affordances and offer parallel access to many different objects, information and tasks. Additionally graspable interfaces can be spatially arranged (cf., Chapter 2.2.2).

Fitzmaurice introduced the division into space-multiplexed and time-multiplexed input devices. The mouse, alongside other generic input devices, is time-multiplexed, hence the same input device is used for different commands at different times. Graspable interfaces however are space-multiplexed by being tightly coupled to a command, function or object and hence "occupying its own space" [77]. This has a second effect: When interacting with a time-multiplexed input device there is always only one item or object selected that can be manipulated. In contrast, with graspable interfaces parallel manipulation is possible. Selection of an item is already carried out just by grasping its dedicated graspable device. Instead of precisely pointing and clicking with for example a mouse cursor, we can make use of our spatial and motor memory [78]. This also leads to shorter interaction sequences as illustrated in Figure 3.1. With generic devices we not only have to acquire the physical device but also map it to the desired "logical device" [77].

Regarding peripheral interaction, studies with graspable user interfaces already show promising results (e.g., [25, 189]). As already stated, graspable interaction offers parallelization of actions [78]. Additionally, graspable user interfaces make use of our haptic perception (cf., Chapter 2.2), which reduces cognitive load during interaction [76]. Consequently Fitzmaurice found an increase of performance when interacting with graspable user interfaces (i.e., space-multiplexed input devices) in contrast to traditional interaction with

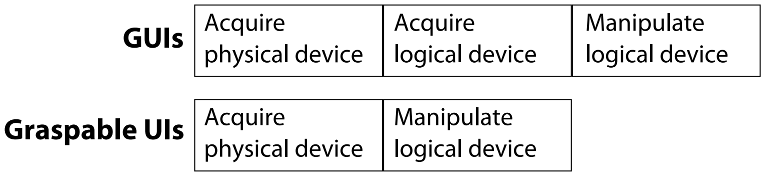

Figure 3.1: Interaction phases for traditional graphical user interfaces (top) and graspable user interfaces (bottom). (Redrawn based on [77].)

graphical user interfaces [77]. However, having a separate input device for several objects or commands of course might be costly, harder to maintain and generally clutter the work space. Nevertheless, Fitzmaurice states that other domains, such as carpentry or kitchen gadgets, are well accustomed to this and therefore is positive that this can be adapted for interaction with digital devices, too [77]. However, the appropriate balance between both extremes – a generic device or many distinct devices – has yet to be found [77].

As proof of concept, Fitzmaurice implemented *Bricks* [78]. Bricks are about the size of a standard Lego brick and are situated on an interactive surface, offering commands such as moving and rotating objects as well as a simple drawing application.

Soon after the introduction of graspable user interfaces Ishii et al. [130] extended the concept in 1997 to **tangible user interfaces** (TUI). Similar to graspable interfaces, tangible user interfaces are connected to digital information and can be grasped and manipulated. Tangible objects cannot only be abstract objects but everyday physical objects. Additionally a tangible user interface also offers information on the current state of the information. While interaction with a tangible user interface is expected to be in the foreground, information can also be displayed in an ambient fashion in the background. Along Weiser's vision [249], tangible user interfaces shall "bridge the gaps between both cyberspace and the physical environment, as well as the foreground and background of human activities" [130]. Hence, the concept of tangible user interfaces in its core definition includes not only graspable devices but the whole physical environment around us can be enriched through digital information connected to it. As an early example, Ishii et al. propose the ambientROOM [131], which incorporates objects that can be grasped and manipulated, ambient displays and soundscapes.

Since the introduction in 1997 the idea of tangible user interfaces gained wide acceptance, however definitions, terminology and accompanying frameworks differ between researchers [169, 216]. Terms used next to tangible user interfaces [130] are, among others, tangible computing [65] and tangible interaction [120, 238]. Most definitions agree that tangible user interfaces offer direct control but also representation [235, 238]. Thus, the user cannot only manipulate content but also perceive the current status of the system. However, the different levels are described for instance ranging from discrete (separate of the TUI) or collocated (combined with the TUI) to embedded (integrated in the TUI) [200]. Representation can be achieved through the physicality itself but also be "computationally mediated" [235], thus not being tangible itself but being transported through the visual or auditory channel.

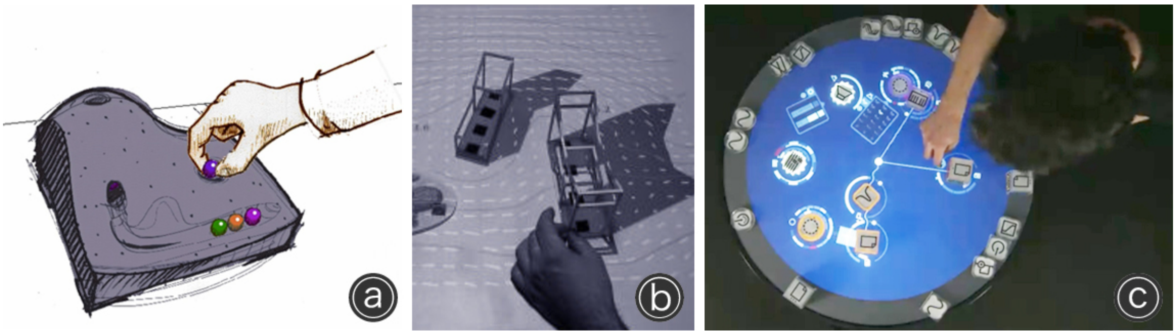

Figure 3.2: Examples for Tangible User Interfaces: (a) One of the very first examples, the Marble Answering Machine [33]; (b) Urp: an urban planning tool [236] from research in 1999; and (c) the reactable [137], a research project that was turned into a commercial product.

3.1.1 Example Applications

Apart from the ambientROOM [131], other early concepts and prototypes did not include the augmentation of a whole room but addressed distinct tasks or objects. The *Marble Answering Machine* [33, 56] designed by Bishop uses marbles to represent messages left on an answering machine. These marbles can later be placed on the answering machine to retrieve the message (see Figure 3.2a). Another early project designed for urban planning – called *Urp* [236] – consists of tangible objects representing buildings, which can be placed on a surface mimicking shadows, reflections and wind flow (see Figure 3.2b). By now research developed many tangible user interfaces for many different use cases and scenarios. One now even commercially available tangible user interface is the *reactable* [137], which can be used to create and perform music (see Figure 3.2c).

3.1.2 Graspable and Tangible Interaction for Peripheral Interaction

Both concepts, graspable interaction as well as tangible interaction, already address some aspects relevant for peripheral interaction. As stated, Fitzmaurice pointed out that graspable interaction offers parallelized input by making use of spatial motor memory and therefore reducing switching costs and cognitive load [78]. Tangible interaction also addresses the transition of focused and peripheral perception. However tangible user interfaces not only include input and interaction through physical devices but also explicitly integrate the visual representation of the associated data or system state. As the focus in this thesis is mainly on peripheral input, the work here – presented in more details in Part II – will mainly refer to graspable interaction. While some prototypes (cf., StaTube in Chapter 6.1) incorporate ambient information about the state of the digital object (here the Skype state) other projects solely focus on the input without incorporating information about the state of the manipulated digital object (e.g., the Peripheral Music Controller in Chapter 7.1).

3.2 Touch Interaction

Touch input already dates back to the sixties, when the first touch screens were developed [136]. These first prototypes were only able to track one single touch at one point in time. However, by now multi-touch is well established. Hence touch input can be characterized in many ways [42]: (1) *direct touch* vs. *remote touch*, (2) *single-touch* vs. *multi-touch*, and (3) *discrete* vs. *continuous* input. The latter describes the difference in just touching an area and thereby selecting it (e.g., a button) in contrast to performing a gesture, which likewise executes a command or performs a selection. Both – discrete and continuous input – is also possible for multi-touch for example when typing on a virtual keyboard pressing "shift" while typing a letter or performing a pinch gesture to zoom. Discrete input is usually based on visual feedback either directly on a touch enabled display (direct touch) or on a display connected to the touch devices (remote touch). Continuous input might also be coupled to visual representations for example manipulating a slider or dragging an item on screen, however, continuous input can also be performed without being coupled with visual feedback, for example when swiping left/right to turn a page. Apart from the location of the touch other parameters – depending on the sensing technology – can be taken into account such as pressure or the angle of approach [42]. Additionally, tap patterns (different number of taps, different rhythms and different amount of fingers) can be used to further express different commands [81]. In contrast, interaction with the mouse is usually constrained to single or double clicks with the left or right button (and sometimes the mouse wheel) [226]. Moreover, touch enabled surfaces can be used for bimanual input and can be divided into distinct areas hence offering "independent 'virtual' devices" [43]. Additionally, gestures without a fixed location can be used to execute commands which are otherwise too far away to reach (e.g., on an interactive tabletop) [89].

Discrete touch input is in many ways similar to click selection with a mouse (although touch input usually does not offer the distinction between hovering and clicking). Gesture based continuous input however is hardly used when interacting with a mouse. In contrast several approaches for gesture based touch interaction are available. It should be noted that some of the research in the area of gesture based input is based on pen input in contrast to touch with the fingers. While we are aware that input with a pen can at best be compared to single touch with the finger [232], we refrain from distinguishing these differences here, as we believe from a conceptional perspective both are based on the same characteristics (direct vs. remote; single vs. multi-touch and discrete vs. continuous). To input text via touch two alphabets Graffiti [49] and Unistroke [83] are well known (see Figure 3.3a). In other contexts different symbols are explored and linked to commands either based on single-stroke gestures [261] (see Figure 3.3b) or multi-stroke gestures [257] (see Figure 3.3c). However, entering gestures is still challenging in terms of accuracy and efficiency [30]. Therefore support through auto-completion and gesture prediction are explored [30]. Apart from technical challenges concerning recognition, especially mapping the diversity of input to one multi-stroke gesture, using more elaborate alphabets includes longer learning phases. While at first this might not seem desirable for peripheral interaction, other rather complex input mecha-

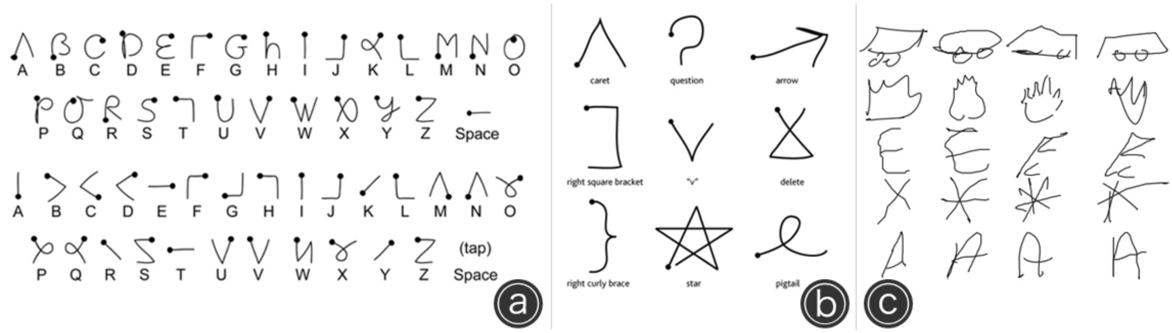

Figure 3.3: Gesture based touch input: (a) Graffiti (top) and Unistroke (bottom) [49]; (b) Single-Strokes Gestures [261] and (c) Multi-Stroke Gestures by different users depicting a car, fire, the letter "E", a star, and the letter "A", showing the difficulty of tracking and mapping these drawings [257]

nisms such as typing can with practice move to the periphery. Thus we believe that more complex stroke pattern can be successfully applied in the periphery for domain experts, who need a rich alphabet and use it intensively thus the effort of learning it pays of. However, for this thesis we focus on simpler touch gestures, minimizing the time to learn mappings between commands and associated strokes.

3.2.1 Example Applications

Johnson [136] built the first touch screen in the sixties (see Figure 3.4a), which was able to recognize one touch point at a time. This changed in the eighties with the introduction of the first multi-touch screens and touch pads. Touch pads in contrasts to screens do not include a visual display but just the sensing device, usually oriented horizontally [42]. The first interactive tabletop – the *Digital Desk* (see Figure 3.4b) – was introduced by Wellner [252] in the beginning of the nineties. The Digital Desk could sense hands and fingers as input and

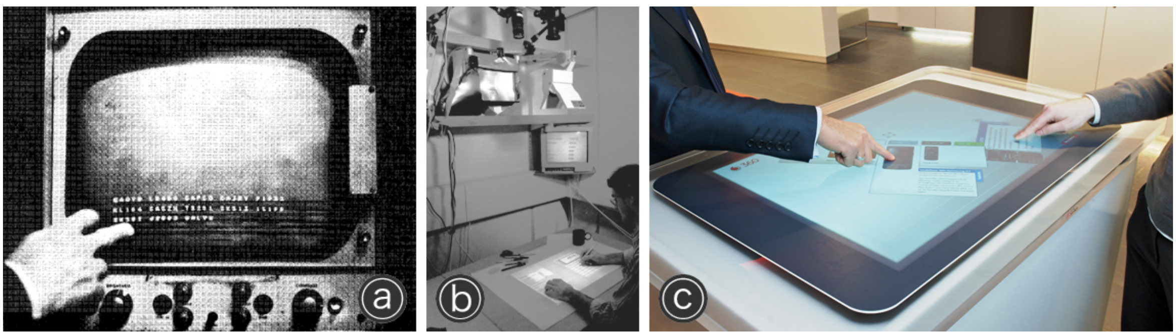

Figure 3.4: (a) The first touch screen by Johnson [136]; (b) the Digital Desk [252], the first interactive table top; and (c) Microsoft's Surface 1, the first commercially available interactive tabletop (press photo by Microsoft)

already showed by now well established concepts such as the pinching gesture. However, commercial success of multi-touch was only achieved in 2007 when Apple introduced the *iPhone* and Microsoft launched the *Surface* (see Figure 3.4c). This very brief historical recap already shows that touch input is available on all kinds of devices with very diverse sizes and properties (e.g., screens, touch pads, tables and even touch enabled floors [14]) and hence based on many different sensing technologies [213], which are outside of the scope of this thesis. More recent projects even go beyond tables, displays and touch pads and explore the body as surface for touch interaction (e.g., [97]).

3.2.2 Touch Input for Peripheral Interaction

As stated, especially continuous input – in some cases – can be accomplished without visual feedback and visual attention, hence continuous touch input is of interest in terms of peripheral interaction. To successfully reduce visual attention touch input should not require a very precise location for the gesture to be performed [42] and should also be easily carried out via remote touch independent of a coupled visual interface. Examples for such low demanding gestures are swiping gestures to navigate through content instead of clicking for example on icons with arrows to go to the next item or the pinch gesture for zooming content [30]. To further reduce precision, touch input is not restricted to input via one fingertip but can also be coarse using for example the palm of the hand [226]. Furthermore, touch enabled surfaces can be integrated in all kinds of devices by now, which offers room for peripheral interaction in many contexts without having to provide additional physical artifacts [43].

3.3 Freehand Interaction

Freehand gestures are an essential part of human communication skills, used – often subconsciously – while talking to emphasize spoken words or also to substitute spoken words (e.g., waving goodbye from a distance) [84]. Gestures operate in two ways: they facilitate listening and understanding but also support the speaker in phrasing her or his words and thereby lower cognitive load [237]. People even tend to gesture when the conversational partner is not able to see them (e.g., when talking on the phone) [32]. However, gestures not only illustrate spoken words but can convey rich information as the usage of sign language among deaf people shows.

Many different categorizations for gestures (not necessarily limited to freehand gestures) exist in HCI. Baudel et al. [28] divide gestural interaction into two groups: *manipulation paradigm* (manipulating content for example in virtual reality with gestures) and *sign language paradigm* (issue commands with gestures). Cadoz [46] divided gestural interaction in three categories: *semiotic* (to convey meaningful information, cf., sign language), *ergotic* (to manipulate the environment) and *epistemic* (to explore the environment through haptic cues). One further classification based on the combination of several theories is presented

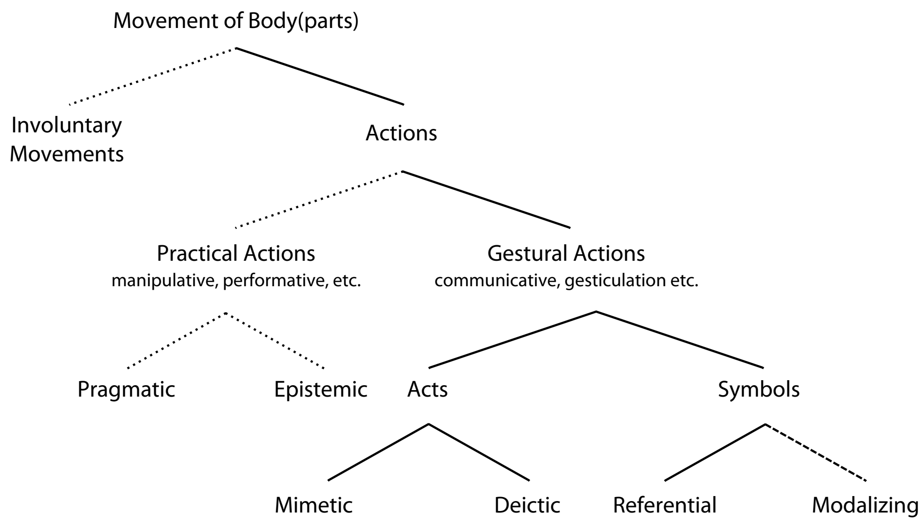

Figure 3.5: Classification of gestures. Solid lines depict gesture types that are used for the prototypes of this thesis. (Adapted and redrawn from [237].)

by van den Hoven et al. [237]. As Figure 3.5 depicts, Baudel's manipulation paradigm or Cadoz's ergotic and epistemic gestures are part of *practical actions* according to this classification. *Gestural actions* here only include "gesticulation and autonomous gestures" [237]. Acts refer to gestures with a close relation to the action – mimicing an action (*mimetic*) or pointing (*deictic*) – while symbols describe gestures, which refer to an action (*referential*) or act as modalizers (e.g., of speech) (*modalizing*). Additionally, Billinghurst et al. [32] names *iconic* gestures (describing the size, shape or orientation of objects) and *pantomimic* gestures (mimicking some interaction such as turning the steering wheel while talking about driving).

Currently most interactions with computers are based on the direct manipulation paradigm [220]. From using freehand gestures, many researches expect a more natural type of interaction, which is expected to be easily learned. However, with a growing number of gestures, remembering different gesture sets might be a problem, and de facto standards such as pinching for touch gestures still need to be established [186]. Moreover gestural interaction is often not self-revealing, that is the user must be aware of the commands the system understands as input [28]. Furthermore, the overall goal is that no input device or augmentation of the user is necessary implying "come as you are" [244] to interact with digital systems [28]. Our bodily capabilities offer a huge variety of possible gestural input, especially concerning eyes-free input [206] (cf., proprioception in Chapter 2.2.1). Nevertheless, freehand interaction over a longer period of time might lead to fatigue in shoulders, arms, wrists and hands [28] and very accurate interaction is hard to achieve because it is hard to position a hand perfectly still in 3D space [28]. Additionally the system often cannot distinguish between intentional and unintentional gestures within the tracked area (immersion syndrome) [244]. If problems arise – with gestures being ephemeral – the user might not get sufficient feedback about the problem [186]. An additional concern is social acceptance, as people often do not feel comfortable to gesture in midair in public spaces. Thus, approaches to increase social acceptance include subtle interactions, which are not easily noticeable by others, or making gestural interaction meaningful, this is, bystanders understand the meaning and effect of gestural actions carried out by another person [179].

A gesture itself can be divided into three phases [71]: the *preparation phase* (moving hand to the location of the gestures), the *stroke* (i.e., the actual gesture) and the *retraction phase* (removing the hand from the location of the gesture). However, the tracking device needs to be able to distinguish these different phases [28]. Tracking in the beginning usually was achieved by the use of data gloves (the first data glove was developed 1987 [32]), today several commercially available solutions, which do not ask for the augmentation of the hands, are available such as optical tracking systems (Microsoft Kinect, Leap Motion) but also capacitive sensing is used. Researchers built systems, which track six degrees of freedom for bimanual interaction [247]. Other solutions include wrist bands [203] or accelerometers [142]. Gesturing while holding physical artifacts, which go beyond a mere sensing device is called tangible gesture interaction [237]. However, for the scope of this thesis we only consider freehand interaction with empty and not augmented hands, to clearly distinguish between the three interaction styles graspable/tangible, touch and freehand interactions.

3.3.1 Example Applications

One of the first systems including free hand interaction is the *Theremin* (see Figure 3.6a), a musical instrument invented 1919 by Lev Termen [4]. With the help of capacitive sensors, which are vertically and horizontally arranged, the musician can control pitch and loudness [32]. *Charade* (see Figure 3.6b), developed 1993 by Baudel and Beaudouin-Lafon [28], is intended to control a presentation. It makes use of a data-glove and 16 gestural commands.

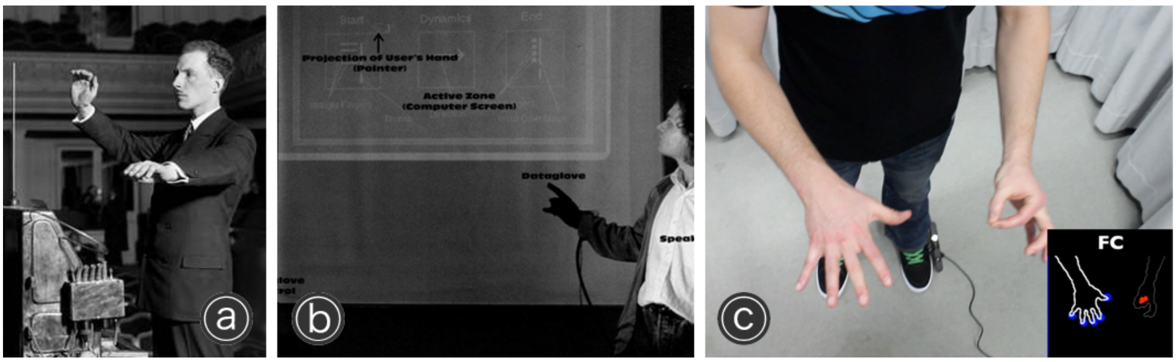

Figure 3.6: (a) A historic example for freehand interaction: Russian inventor Lev Termen playing the Theremin[a]; (b) A presenter controlling his presentation with one of the first research projects in the context of freehand interaction – the Charade data glove [28]; and (c) a recent project showing a user interacting with ShoeSense [18].

[a] Image Source: https://en.wikipedia.org/wiki/File:Lev_Termen_playing_-_cropped.jpg (Last Accessed: 26.06.2013)

To overcome the immersion problem, only gestures carried out while pointing to the screen are considered as input. When testing the system, they found that trained users could use the system with a recognition rate of 90% to 98% (compared to untrained users with 72% to 84%). *ShoeSense* [18] (see Figure 3.6c) is a more recent example, which uses a shoe mounted tracking device (a depth sensor). Possible interaction scenarios stated by the authors include carrying out commands, which are issued frequently but in a discrete way, offering additional interaction possibilities for mobile phones but also artistic performances. Apart from these three examples, there are many other application areas, which try to incorporate freehand gestures, above all gaming (cf., commercial products such as Microsoft Kinect) but also medical systems [244], authentication [168] or the automotive context [159] start to make use of gestural input. However, gestural input in 3D space is not only restricted to input by the hands (cf., foot based gestures [5, 214]) but this is outside of the scope of this thesis.

3.3.2 Freehand Gestures for Peripheral Interaction

As stated, freehand gestures rely on our bodily capabilities such as proprioception and spatial memory. Hence, freehand gestures include inherent feedback [253] and can be carried out in an eyes-free manner [206], which is one aspect of peripheral interaction. Problems which might arise when interacting in 3D space such as fatigue are not very likely to arise as peripheral interaction is intended as episodic and quick interaction. However, there are no well-established gestures yet on which peripheral interaction can build (cf., for touch interaction swiping to browse through content). Gestural input hence has to be revealed to the user and be practiced. But as peripheral interaction is especially well fit for tasks that are executed repeatedly and often, learning a gesture set can be achieved quite fast (cf., interaction with the Peripheral Music Controller in Chapter 7.1). In this thesis, we will examine freehand gestures, which belong to the sign language paradigm and can be best categorized as semiotic or more detailed as mimetic, deictic or referential gestures.

Chapter 4

Systems: Linking Human Capabilities and Interaction

Synopsis

Peripheral interaction being a new research area is inspired by several other fields: Eyes-free interaction aims at reducing visual attention during interaction. This is achieved by replacing visual cues through auditory or haptic feedback but also by new interaction styles such as freehand or touch gestures. Systems investigating eyes-free interaction usually only address the reduction of visual attention but not necessarily cognitive load. Microinteractions are designed to reduce interaction duration with devices to four seconds or less, ideally while carrying out another task and therefore often having only limited freedom of movement of hands and fingers. Ambient information also targets the periphery of attention but for perception and not for active input. However, several interactive ambient information systems do exist, but interactivity there either is implicit or asks for the users focus. Peripheral interaction is inspired by all these fields and combines their ideas to offer explicit interaction in the visual and attentional periphery, which is brief and hence reduces interruptions from the primary task. Next to conceptional explanations for these four fields – eyes-free interaction, microinteractions, ambient information and peripheral interaction – this chapter introduces several example applications for each research area.

The term "Peripheral Interaction" was introduced by Darren Edge in 2008 [69]. Hence this type of interaction is rather new and does not look back onto a huge scope of research and related work. However, related fields evolved in parallel inspiring the work in the area of peripheral interaction. All related fields explored in this chapter rely on explicit interaction (although not solely). Implicit interaction, in contrast, is defined as "an action, performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input" [211]. Hence a person might be interacting with a system but is not necessarily aware of it and did not consciously initiate this interaction [139]. We believe that implicit interaction is one important step to decrease cognitive load for tasks, which can be carried out by a computerized system alone. However, peripheral interaction is intended for tasks that are explicitly initiated and controlled by the user, but still shall reside in the periphery of attention and hence only cause very limited cognitive load.

The previous two chapters introduced human capabilities (Chapter 2) and three interaction styles (Chapter 3). This chapter introduces a selection of different research fields, which in parts overlap with peripheral interaction and which link human capabilities and interaction styles. Eyes-free interaction tries to minimize visual attention during interaction, microinteractions aim at minimal movements as well as very short interactions, and ambient information systems use the periphery of attention to perceive information. While other fields, such as attentive user interfaces, body-centric interaction or instrumented environments to name a few, also might touch peripheral interaction, we consider the here listed fields the most related and thus most inspiring for peripheral interaction. Eventually we will give an overview of the related work in the field of peripheral interaction, which uses elements of all before mentioned fields to offer interaction in the cognitive and visual periphery of attention through short interactions.

4.1 Eyes-Free Interaction

Eyes-free interaction [188] aims at interaction without a graphical user interface or visual feedback. With devices getting smaller and smaller there is often not enough space left for an elaborate user interface. Even if there are displays, we can observe a trend towards fewer and fewer hardware buttons (cf., smart phones), which used to offer operation without visual attention through haptic cues. Additionally, computational devices get more and more mobile. While on the move, visual attention often has to be dedicated to other tasks (such as being save on the street) than interacting with an interactive device. Nevertheless, people still often want to (e.g., to select another song to listen to) or have to (e.g., to navigate to their destination) interact with their devices. Yi et al. [265] classified motivations for eyes-free interaction along four categories: environmental, social, device feature and personal. *Environmental* motivations include motives such as safety during interaction but also extreme lighting conditions in which displays are hardly readable. *Social* aspects for eyes-free interaction are to avoid interruptions while engaging with other people but also to keep information private. *Device Feature* aims at constraints such as small screens or the possibility to multitask (e.g., holding the phone to the ear and talking to somebody but at the same time checking the calendar on the phone to arrange an appointment). Eventually, *Personal* motivations range from entertainment to lower perceived effort when interacting eyes-free (e.g., the mobile phone can be in the pocket while interacting with it).

As this classification already shows, there is more to eyes-free interaction than just interacting without a visual representation. Two different trends in the scope of eyes-free interaction can be seen. The one focuses on replacing visual feedback through audio or haptics, while the other tries to develop new input techniques, which can be carried out without visual attention [188]. One drawback of current eyes-free input is that – in contrast to graphical user interfaces – eyes-free interfaces do not offer exploratory learning of the interface. Users usually have to know how to interact with the system to successfully achieve their goals [188]. Generally eyes-free input makes use of proprioception (cf., Chapter 2.2.1) and often uses this capability as the only feedback for the user [188], however, as already stated, additional information through audio (e.g., [39, 267]) or haptic feedback (e.g., [153, 156]) can also often be found. Moreover, first researchers in the domain of eyes-free interaction acknowledge the need to not only design for eyes-free interaction but also for low cognitive load [188] to offer the possibility to multitask more easily. This is very much in line with the goals of peripheral interaction. However, only very few eyes-free systems currently are designed with this premise and even less evaluated concerning mental and cognitive load.

4.1.1 Example Applications

EarPod [267] uses touch to select items in a radial menu. The radial menu consists of an outer ring, which stores up to twelve items and an inner circle, which can be used to cancel a selection. EarPod uses auditory feedback to support discovery of menu options, however, trained users are able to select known areas without visual and auditory cues. Brewster et al. [39] implemented the *Gesture-Driven 3D Audio Wearable Computer*, which tracks head gestures, such as nodding or shaking the head, to select items in a radial menu. The system is intended to be operated while walking. Participants in a study performed better when additionally receiving audio feedback. *Nenya* [12] is a magnetic ring, which can be worn like a wedding ring and hence offers not only eyes-free but also concealed input (see Figure 4.1a). Many people tend to play with their rings, but Nenya understands such interactions (e.g., sliding the ring along the finger or turning it) as input. Next to the ring a user has to wear a sensor around the wrist to track this interaction. The authors showed that participants were able to identify up to eight commands without any additional visual hints. Even less intrusive are *EMG-based Motionless Gestures* [55], which are activated by muscle tensions. An armband worn around the upper arm tracks nearly invisible gestures. *WatchIt* [192] uses the wristband of a watch for interaction (see Figure 4.1b). Apart from eyes-free interaction WatchIt also addresses the minimal screen space on smart watches and the fat finger problem, which is especially severe on such small screens. Gestures, such as swiping along the wristband or pressing distinct locations, are supported. *Point Upon Body (PUB)* [155] uses the body as input area (see Figure 4.1c). By tapping on different regions on the forearm

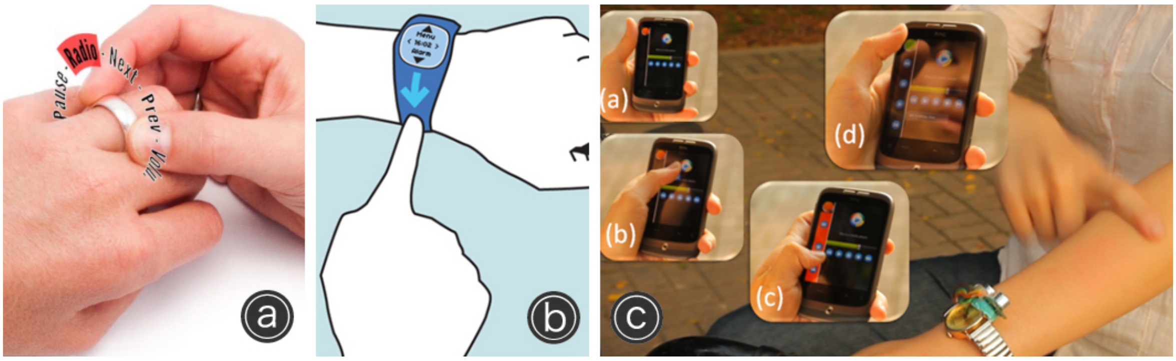

Figure 4.1: Example applications for eyes-free interaction: (a) the magnetic ring Nenya [12]; (b) WatchIt [192], an interactive wristband attached to a watch; and (c) Point Upon Body (PUB) [155] to control a mobile device.

commands can be executed. While the division is individual for each user, most users are able to divide their arm into six regions. Proprioception (c.f., Chapter 2.2.1) offers enough feedback to select these regions eyes-free. Two example devices can be controlled by PUB (implemented with the help of an ultrasonic device) – a remote display and a mobile device.

4.1.2 Linking Capabilities and Interaction

In reference to the previous two chapters, these examples illustrate that the range of projects in the field of eyes-free interaction is pretty broad using for example touch (e.g., [267]), gestures (e.g., [39]), jewelry (e.g., [12, 192]) or the body itself (e.g., [155]) to offer interaction without visual attention (cf., Chapter 2.1.1). Thus, these projects offer a high variance of input styles as inspiration for peripheral interaction. However, even if these projects and interaction styles achieve eyes-free interaction, little is known about the cognitive load imposed by them, especially when depending on audio feedback guiding the user through the application (e.g., [267]). Investigating some of these interaction styles – namely graspable, touch and freehand interaction – in more detail, will shed light on the question whether these interaction style can be used for eyes-free interaction only or also for interaction with only minimal cognitive attention.

4.2 Microinteractions

Microinteractions are defined as "tiny burst[s] of interaction" [13] or "short-time manual motor interruptions" [262], which are completed in (less than) four seconds [13]. Microinteractions are designed to enable interaction with small devices [227] or as parallel interaction alongside another (manual) primary task [262] and while on-the-go, as interaction while moving is already fragmented into four-second segments independent of the device being designed to support short interactions [190]. Ashbrook, who was one of the first to coin the term microinteractions, already states that these short interactions should be able to be carried out "almost thought free" [13]. Additionally, if possible, microinteractions should also be able to be carried out eyes-free [156]. To achieve that, Loclair et al. propose "single-purpose functions rather than menu navigation" [156] for micro interacting with a device. Ashbrook [13] however suggests microinteractions for tasks such as checking the calendar or the weather on a mobile device. While usage time for different applications may vary, access time should be minimized according to Ashbrook. To achieve that, he investigates touch-based and motion-based gestures for microinteractions.

Wolf et al. [262] examine microgestures (as a subclass of microinteraction) carried out by the fingers in parallel while grasping other devices in more detail and offer a taxonomy. They define three basic grasps – palm (e.g., grasping a steering wheel), pad (e.g., grasping a card while inserting it into an ATM) and side (e.g., when writing with a pen) – and evaluated, which finger movements could be carried out while performing one of these grasps. Especially interesting in the context of peripheral interaction is the fact that they not only assessed, which gestures are ergonomically possible but also how much mental load these gestures impose on the user, based on the experts' ratings. For example they found that tapping while performing a palm-grasp can be performed with little attentional resources, but executing pressure imposes more cognitive load. These findings could for example be used to design secondary tasks, such as controlling the radio or the navigation, while holding the steering wheel and driving. One limitation of course is the distinction between intended gestures and random movements. Tapping for example might occur when being immersed in the music played on the radio.

4.2.1 Example Applications

Tickle [263] is one example application, which makes use of microinteractions on different shaped surfaces (flat, convex or concave). With the help of a finger ring or lacquer on the

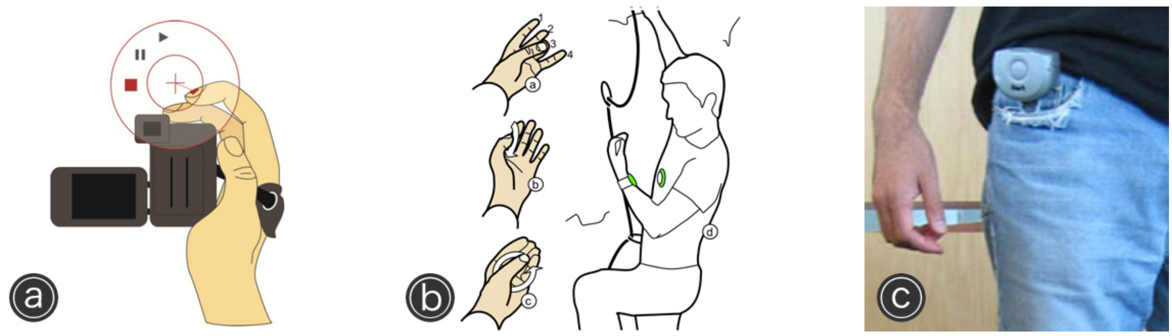

Figure 4.2: Example applications for microinteractions: (a) Tickle [263], investigating microinteractions on different shaped surfaces; (b) PinchWatch [156], enabling microgestures during rock climbing; and (c) Whack Gestures [125], interacting with a device by stroking it.

finger nail, input can be tracked. For example while holding a camera (see Figure 4.2a) users can perform four different gestures (tap, release, swipe, and pitch) to execute commands. *PinchWatch* [156] is introduced in the context of rock climbing, which only leaves room for very quick interactions while clutching onto the rocks. PinchWatch is located at the wrist while the interaction is captured by a chest-worn camera (see Figure 4.2b). To interact, users perform gestures with their thumb on the respective palm. Hence the device can be operated with one hand only and no device needs to be grasped. The bodily feedback of touching the own palm additionally enables eyes-free interaction. *Whack Gestures* [125] are not formally called microinteractions by the authors, but fulfill the previous definitions for microinteractions. Whack Gestures are "inexact and inattentive" and use "gross movements" [125]. To initiate a command a device mounted at the users belt is stroked by the palm, which is tracked by an accelerometer (see Figure 4.2c). To minimize false positives, a signaling whack gesture has to be performed before the actual command.

4.2.2 Linking Capabilities and Interaction

Microinteractions are designed to be executed alongside other tasks, such as grasping a device (limiting manual capabilities) or walking (limiting visual and cognitive attention), thus making use of divided attention (cf., Chapter 2.1.1). Prototypes involving microinteractions are intended to foster short, parallel, nearly thought free and if possible also eyes-free interaction. All these characteristics also apply to peripheral interaction. Especially of interest is the fact that for some projects mental load that is imposed by microinteractions was measured [262]. Generally, microinteractions rely on touch and freehand gestures, hinting that these interaction styles might also be applied to peripheral interaction.

4.3 Ambient Information

Ambient information systems [197] is just one name for a group of systems, which sometimes are also called peripheral display [90], awareness systems [241] or notification displays [171]. While definitions slightly vary between these systems, they all have in common that they want to make information available in the periphery of the users' attention [111] in parallel to other tasks [90]. Thus, the users are made aware of information – "by blending [it] smoothly into the surrounding environment" [108] – but are not focused on it [166]. Usually ambient information systems just convey very limited [223] and not complex [88] information, to be perceivable in the periphery. However, ambient information can also move to the focus of attention if relevant [197]. Ambient information is often presented in an abstract and aesthetic way [161] "manifesting itself as subtle changes in form, movement, sound, color, smell, temperature, or light" [131], however, most ambient information systems target the visual channel to convey information.

Gross [88] proposed design guidelines for ambient information systems. According to these guidelines, interfaces conveying ambient information need to be *effective* (making aware without disturbing), *efficient* (speeding up interaction), *safe* (undesired situations should not occur), *utilitarian* (offering the right kind of functionality), *easy to learn/remember*, *visible* (access to the information whenever needed), *offering feedback* (especially when not only offering awareness but also interaction), *constraining* (keeping information simple), *adequately mapped* (especially between input and output), *consistent* (within the system itself but also to previous knowledge), *adequate* (for the desired domain), *participatory* (during design and development).

Pousman and Stasko [197] proposed a taxonomy for ambient information systems based on four design dimensions: Information Capacity, Notification Level, Representational Fidelity, and Aesthetic Emphasis. *Information Capacity* describes the "number of discrete information sources" [197] in an ambient information system. While some systems only display one single information (e.g., Dangling String [249]) others display a multitude of information channels at once. For some of these systems, such as InfoCanvas [174], users can configure the number of information sources. *Notification Level* describes to which extent the system is designed to interrupt or notify the user. While some systems require the user to actively look at the display to perceive subtle changes (e.g., slow animations; cf., Lumitouch [50]), others include notifications through animation (e.g., blinking, cf., Slideshow [45]) or auditory cues (e.g., [266]). *Representational Fidelity* categorizes the encoding of information. Based on semiotics, Pousman and Stasko propose to classify representation into symbolic (abstract, letters, numbers, etc.; cf., Information Percolator [111]), iconic (metaphors, drawings, etc.; cf., Informative Art [118]) and indexical (maps, photographs, etc.; cf., InfoCanvas [174]) signs. Finally, *Aesthetic Emphasis* describes the aesthetic value of a display. While some systems value an artistic and aesthetic appearance (e.g., Informative Art [118]), others just focus on a functional display (e.g., [170]). Based on this classification, Pousman and Stasko [197] depicted four main archetypes in the scope of ambient information systems: *Symbolic Sculptural Display* (e.g., Information Percolator [111]), *Multiple Information Consolidator* (e.g., InfoCanvas [174]), *Information Monitor Display* (e.g., Slideshow [45]), and *High-Throughput Textual Display* (e.g., My Yahoo[1]).

4.3.1 Example Applications

All kinds of data is represented by ambient information systems. Weather forecasts, bus schedules, and information about the presence of colleagues and friends are just a few examples. Since the introduction of the *Dangling String* [250] in 1997, many different ambient information systems have been built ranging from complete **rooms** such as the *ambientROOM* [131] (cf., Chapter 3.1) to displays and physical artifacts displaying publicly available but also personal information.

[1] http://my.yahoo.com (Last Accessed: 03.06.2013)

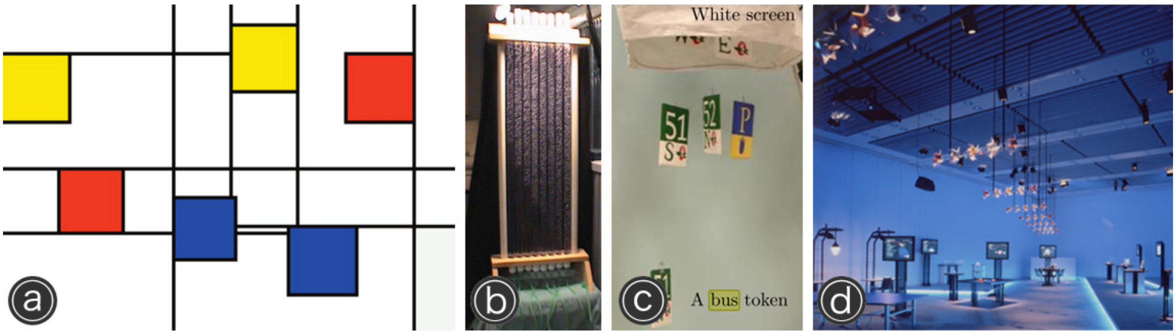

Figure 4.3: (a) Informative Art [118], showing the temperature of six cities depicted by squares (position is based on the location on a world map); (b) the Information Percolator [111], rendering images through air bubbles; (c) Bus Mobile [161], displaying nearby buses; and (d) Pinwheels [129], a large scale installation visualizing network traffic.

One example for an **ambient display** is the *Digital Family Portrait* [180], which is designed for families who want to stay updated on the well being of their elderly relatives. A picture frame, intended to blend in with the regular home decor, is enhanced with icons displayed on the frame. Icons change according to the current welfare of the relative. Data for this display shall be collected by sensors in the final prototype. Another display based example is *InfoCanvas* [174], which can be customized to represent different information sources – such as weather forecast, traffic conditions or email notifications – as visual collage. *Informative Art* [118] is inspired by artistic paintings. For example the style of Piet Mondriaan is used to visualize information such as the weather (see Figure 4.3a).

Apart from ambient displays, many different **physical artifacts** have been built to convey ambient information. The *Information Percolator* [111] uses air bubbles in water filled tubes to display information. The bubbles act as pixels displaying black and white images, which move through the tube from bottom to top (see Figure 4.3b). *Bus Mobile* [161] offers information about upcoming buses. The closer a token, representing a bus, gets to the top the closer it is to the nearest bus station. Only buses, which will reach the station in the next 25 minutes, are visible (see Figure 4.3c). The last example is *Pinwheels* [129], which reminds one of the Dangling String [250]. In a museum installation with 40 pinwheels, the "wind of bits that blows from cyberspace" was visualized (see Figure 4.3d).

4.3.2 Interactive Ambient Information Systems

All examples mentioned up to now only present information. The user cannot interact with this information. However, there are several examples in the scope of ambient information systems, which also incorporate input possibilities, covering both – implicit and explicit interaction. Again, projects can be divided into display based projects and physical artifacts.

On example for a **display based** project is *LumiTouch* [50]. Similar to the Digital Family Portrait [180], the prototype consists of a picture frame. By being close to the picture frame, hence by implicit interaction, the remote person is informed through an ambient glow. Additionally, by (explicitly) squeezing the frame, the remote picture frame lights up. The *Ambient Dayplanner* [266] shows the current time and close by appointments projected on the wall. With the help of a tangible user interface the reminder time can be explicitly set. Three different prototypes – *Picture Navigation* [208], *Hello.Wall* [198] and *Interactive Public Ambient Displays* [242] (see Figure 4.4a) – investigate the use of (three or four) zones for structuring interaction. All three prototypes consider the outer zone to be the ambient zone in which the display solely acts as ambient information display. The next zone is used to attract the user's attention and communicate that interaction is possible, hence the system already reacts to implicit interaction. The closest zone (or for Interactive Public Ambient Displays [242] the two closest zones) offers explicit interaction, for example through touch [208, 242], additional devices [198] or freehand gestures [242].

A **physical artifact** representing ambient information but also offering interaction is *Hangsters* [191]. A physical representation of the user can be tied to a string (see Figure 4.4b). By pulling it down or pushing it up one can react to a conversation or initiate one via instant messaging. *SnowGlobe* [241], similar to Picture Navigation [208], offers remote presence indication. Just by being close to the globe a remote globe lights up and snows. Additionally, by shaking the globe, one can explicitly light up and start the remote snow more intensively. *Cubble* [144], a cube shaped object, also supports bi-directional communication between two distinct people. Designed for partners in long-distance relationships, partners can light up the remote cube by tapping on it. *Clouds* and *Follow the Lights* [109] are connected large-scale installations (see Figure 4.4c). Lights on the floor are designed to lure passing by people to take the stairs instead of the elevator. Spheres hanging from the ceiling indicate how many people took the stairs compared to the elevator. As passing by people were not made aware of the installation, they relied on implicit interaction.

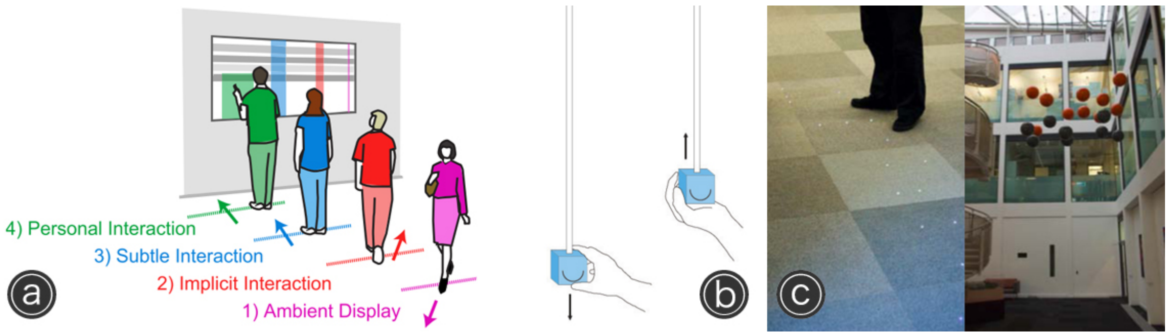

Figure 4.4: (a) Interactive Public Ambient Displays [242] and their corresponding interaction zones; (b) Hangsters [191], which can be pushed up or pulled down to react to or initiate conversations via instant messaging; and (c) Follow the Lights & Clouds [109] luring people to the stairs and indicating how many people took them.

4.3.3 Linking Capabilities and Interaction

Ambient information systems are designed to be perceived in the periphery (cf., Chapter 2.1.4) with only minimal attention.Already, several prototypes try to overcome the rather passive usage of just perceiving information and add active input to their prototypes. However, compared to peripheral interaction, these interaction possibilities are either implicit, hence not consciously controlled by the user, or they are focused interactions, thus drawing the users attention towards it. Only few interactions, for example pulling down the Hangster [191] avatar, might be performable in the periphery of the users attention. However, researchers did not address that explicitly in their design and consequently did not evaluate it.

4.4 Peripheral Interaction

In the previous subchapters, we introduced different fields, which are related to peripheral interaction and cover some aspects of peripheral interaction such as interacting with minimal visual attention. The term peripheral interaction however was first coined by Edge in 2008 [69]. He states: "In peripheral interaction, users are free to arrange independently-meaningful, digitally-augmented physical tokens on the periphery of their workspace and away from their normal centre of attention, ready to selectively and fluidly engage those tokens in loosely related, dispersed episodes of digital, cognitive, and social use" [69]. In 2009 he adds to this, that interaction is not carried out "through precise manipulations of a computationally-interpreted spatial syntax, but through imprecise interactions" [70]. Edge hence defines peripheral interaction to be carried out through coarse interaction with tokens, which usually are not in the focus of the attention but which occasionally move to the center for quick interactions. Olivera et al. define peripheral interaction in a slightly stricter way: "Peripheral Interaction is brief because our interaction focus is somewhere else and [...] we want to deal with it without strongly affecting the main one" [189]. Hence, they expect the interaction to stay in the attentional periphery even during active interaction. Bakker et al. also declare that peripheral interaction is intended to "take place in the background or periphery of the attention" [26]. This should "enable digital technologies to better blend into our everyday lives" [22] by requiring "interaction to be simple and straightforward, so that it can embed in the everyday routine, rather than having users adapt their routine drastically" [23]. They also acknowledge that interaction can "shift between the center and periphery" [25]. The evolved definition, considering peripheral interaction as interaction that is carried out in a coarse way in the periphery of the (cognitive and visual) attention often parallel to other tasks but might move to the center of attention in particular situation, is in line with our definition (cf., Chapter 1.1.3). All these definitions built on Weiser's and Brown's vision of calm technology, which "engages both the center and periphery of the attention and in fact moves back and forth between the two" [249]. Hence, peripheral interaction is motivated by the idea of offering additional input capabilities, which can be carried out alongside other tasks with minimal attention to reduce interruptions.

Pohl et al. [196] investigated focused and casual interactions. They did not root their argumentation in the context of peripheral interaction, nevertheless their work fits very well. They propose to offer different interaction techniques, for interaction with a varied degree of attention and effort, depending on the current circumstances, to offer a continuous interaction space from focused to casual interactions. Pohl et al. motivate casual interactions by *physical reasons*, such as the hands being occupied by another task, wearing gloves or being handicapped, *social reasons*, such as being on a date or in a meeting, and finally *mental reasons*, such as distractions by another task or tiredness after a long working day. These reasons largely overlap with the motivation for the previously mentioned research areas eyes-free interaction (cf., Chapter 4.1), microinteractions (cf., Chapter 4.2) and ambient information systems (cf., Chapter 4.3) and can also be applied to peripheral interaction.

Bakker et al. [22] carried out a context mapping study and collected 285 quotes to analyze peripheral tasks in the physical world to get a deeper understanding of people performing tasks in the periphery. The statements were clustered in three types of activities: *sensorial*, *cognitive* and *bodily* activities. Most activities, however, were categorized as bodily activities (204 out of 285 quotes), which were mostly (167 quotes) carried out by the hands. Additionally activities were clustered in four categories: main activities, temporary side activities internally triggered, temporary side activities externally triggered, and ongoing side activities. *Main activities* are usually tasks that have been carried out very frequently beforehand and therefore turned into routines, which do not require very much cognition to be performed. Again most of these activities are bodily activities such as ironing, taking a shower or eating. Sensorial and cognitive activities, which are categorized as main activities are considered to be peripheral because they are done to relax (e.g., watching a dull soap on TV). Most main activities were started in the center of attention, however as they were routines shifted to the periphery during execution, and might switch between the center and the periphery during the course of execution. *Temporary side activities internally triggered* are (usually short) tasks, which are carried out during the execution of another task and are triggered without any external stimulation. These tasks usually do have a distinct goal but are not necessarily related to the main task. Still, most activities were bodily activities such as opening curtains or putting things in a bag. This activities are often habits or rituals and people often forget that they just did it (e.g., one participant stated to regularly check if her earrings are still there). Additionally, there are *temporary side activities*, which are *externally triggered* by sensorial stimuli, such as seeing the open toothpaste while entering the bathroom and automatically closing it. Hence, these tasks are not habituated but triggered by the environment and might be related to the primary task. Again these activities are short and mostly bodily. The last category describes *ongoing side activities*. This is the only category where bodily activities are not the dominant type of activities. A typical ongoing activity is listening to the radio, for example while cooking. Of course attention here can vary again between these two tasks and listening to the radio might move to the focus for example while listening to the news.

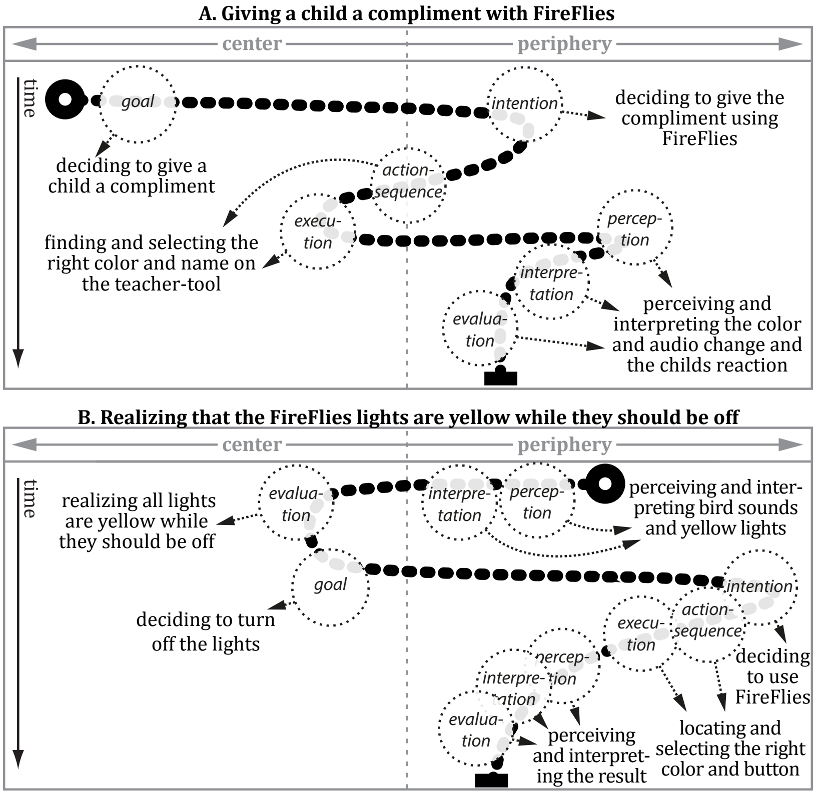

Figure 4.5: Two examples showing teachers interacting with FireFlies, a system by Bakker et al. [23, 25] that enables teachers to turn on light objects for each pupil to communicate individual or group messages during lessons. Based on Norman's action cycle [185], phases of the interaction are spread between the center and periphery of the attention depending on the task and the current circumstances. (Image taken from [19].)

Several suggestions to take into account, when building interactive systems, which support peripheral interaction, have been proposed. Interaction can fluently move between the center or periphery. Hence an interactive system shall support different levels of interaction [196]. Bakker et al. showed in Figure 4.5 how interaction with a device (here FireFlies [23, 25], a tool which enables teachers to turn on individual light objects for each pupil to communicate messages to individual pupils or the whole class, cf., Chapter 4.4.1) can move between the center and periphery. Phases are based on Norman's action cycle [185]. Figure 4.5a shows the execution with the interactive device being carried out in the center of attention (here, the teacher uses the individual light objects to give compliments to children, thus turning on a light for one child tells the respective child that he or she is doing well), while Figure 4.5b shows a scenario with the same device, the teacher now uses the device in the periphery (because she realizes that some lights are still on, although she wants them all to be turned off). Potential reasons for interactions – or part of interactions – moving between the center and periphery are *habituation* (being used to the device or task), *difficulty* (of task execution), *significance* (how important or crucial is the task), *salience* (stimuli triggering interaction) and *affection* (enjoyment of interaction, cf., gaming) [19]. For an interaction to become peripheral, old habits – which might not have been in the periphery – also have to be unlearned to adapt new habits based on the peripheral device [19]. Additionally, researchers and designers should consider the device and context in which a system is deployed [196]. Interaction with a device might be carried out in a rather chaotic environment (e.g., while on the go) and hence might be interrupted, even though the interaction can be carried out in the periphery. Additionally, some contexts might block certain senses and cannot be used probably because of the current primary task [189]. Moreover, peripheral interaction is personal [19], meaning not every design works well for everybody to truly blend into the periphery. Making design configurable could help to overcome this problem.

4.4.1 Example Applications

Four prototypes were published that have been labeled by the authors as prototypes designed for peripheral interaction. These prototypes all can be roughly categorized as graspable or tangible user interfaces (cf., Chapter 3.1).

Edge and Blackwell propose a *Task Management System* [70]. Figure 4.6a shows the system, which consists of an interactive surface, augmented with tokens, and a single knob. A camera positioned above the surface tracks the tokens that are put on the surface. On the surface's display the tokens are enriched with halos displaying additional information about them (e.g., end date, duration). The task management system is operated bimanually, meaning one hand manipulates the tokens while the other hand is located at the knob for fine-grained interaction. The system was evaluated by three participants for five weeks in their daily office life. Next to interaction, it was used to regularly glance at the display to obtain an update on the elapsed and remaining time. Participants stated that they could operate the system while only glancing at the devices.

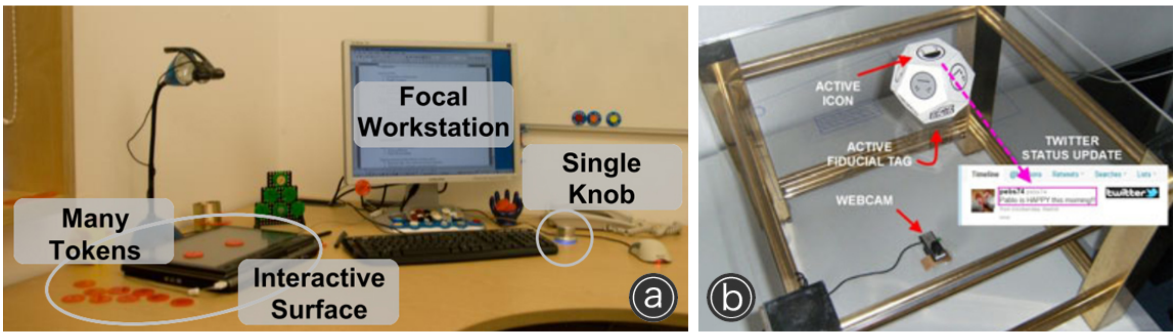

Figure 4.6: (a) Task Management System [70], operated bimanually with the tokens on the interactive surface and the knob; and (b) PolyTags [189], used to post updates to a social network or to control an intelligent environment by turning the multi-faced dice.

Figure 4.6b shows *PolyTags* by Olivera et al. [189]. Two different PolyTags were built: One for controlling the status in social networks and one to control an intelligent environment (e.g., turning on the TV, or the heater). On two opposite sides a human-readable icon (or word) and a Fiducial marker (machine readable 2D code) are located on the multi-faced dice. By turning the PolyTag one controls the system (a camera below the table reads the marker and acts upon it). PolyTags were evaluated in a lab study. Participants were asked to count vowels in a text as distraction task while being asked to carry out several status updates or controlling the intelligent environment. Participants made fewer errors counting the vowels while using the PolyTags compared to a traditional GUI. This might indicate that distraction during the counting task was lower when interacting with the PolyTags.

The following two designs were built by Bakker et al. to help teachers in class. *NoteLet* [26] supports teachers in observing children, which is done during class. Usually teachers have to return to their desk to take notes of observations, which they later transcribe on the computer. NoteLet is a bracelet, which is worn around the wrist (see Figure 4.7a) and offers two different modes to take pictures of the class (with the help of a camera, which is mounted in the corner of the room) to remember observations. By squeezing the wrist, a picture with a timestamp is taken. To additionally store the name of the child the observation is about, all names of the children in the class are listed on the back in alphabetical order, with girls listed on the right, and boys left. Next to each name a touch sensitive area is located. The touch sensitive area is overlaid with different fabrics depending on the grade of the children (first and second grade were taught together in this case) to offer haptic cues. The system was evaluated for two weeks. The bracelet was only worn for a selected time frame by the teacher, when she usually observed children. Most pictures that were taken during that time also incorporated a child's name, which was considered easy but still took a few seconds to find the desired name. NoteLet seemed to integrate well into the teacher's routine but still the interaction to select a name – at least during the two weeks deployment – could not shift to the periphery. However, just taking a picture without a name could be carried out very briefly, but lacked information.

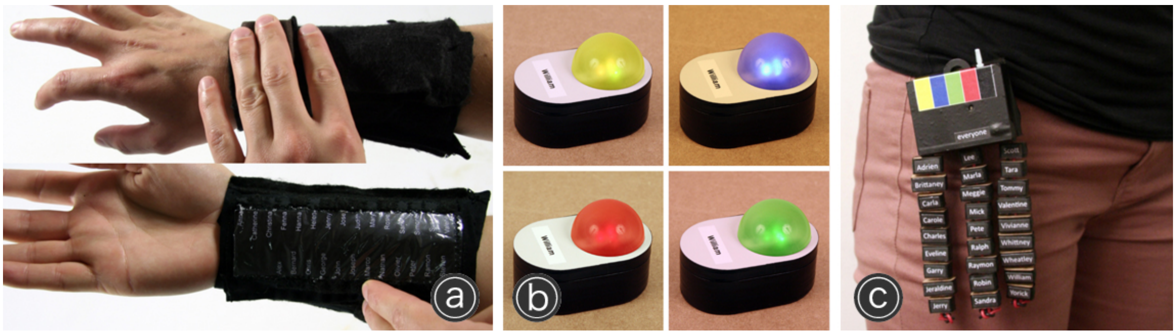

Figure 4.7: (a) NoteLet, to take photos in class by squeezing the wrist (top) or touching a distinct area to add the name of a pupil to the meta-data (bottom) [26]; (b) FireFlies' light objects, located on every pupils desk [19]; and (c) FireFlies' teacher tool clipped to the clothes of a teacher to control the light objects [25].

The second system designed for teachers is *FireFlies* [23, 25] consisting of light objects, placed on every child's desk (see Figure 4.7b) and a teacher tool (see Figure 4.7c), which is used to turn the lights on and off and switch colors (between yellow, blue, green or red). The teacher tool consists of a little box, which can be clipped on clothes to carry it with oneself during lessons (however usually FireFlies was lying on the table or held in the other hand during interaction), with a slider on top to select the color. On the bottom beads represent every child in class. By squeezing one of these beads the respective light object lights up. Moreover there is a button to switch on all lights at once. Additionally a soundscape is giving feedback about the colors of the light objects. Light objects could be set individually or altogether. Intended as open-ended design, participating teachers were not given any instructions about the use case of FireFlies. Hence, they were free to decide when and how to use the prototype. During a six week deployment in four different classes, FireFlies was used for several different secondary tasks such as giving a compliment or turn taking. Teachers, after some time getting used to it, integrated it well into their daily routines, replaced old habits with the new system, and even stated to miss it after the evaluation phase was over. However, selecting a bead of a distinct student required some effort, while performing a stack of tasks (e.g., changing several light objects one after another) was comparable to the effort of doing math in front of the class. Thus requiring a noticeable amount of mental resources.

4.4.2 Linking Capabilities and Interaction

Although the previously presented prototypes differ hugely in form and use case, all these prototypes can be categorized as graspable or tangible user interfaces (cf., Chapter 3.1). Researchers justify their decision to select tangible objects, because in our physical daily life, we also use physical tools to perform actions in the periphery [26] (cf., Chapter 2.1.4), and because this "physicality opens up a parallel interaction channel" [189] (cf., Chapter 2.1.1). Additionally they offer spatial arrangements supporting users in orienting in the periphery [69]. However, findings in other related disciplines suggest that other interaction styles (cf., Chapter 3) are also possible. For example gesture based interfaces are regularly used for eyes-free interaction (e.g., [39]) as well as touch (e.g., [192]). The same holds true for microinteractions, which also use touch (e.g., [263]) and gestures in 3D space (e.g., [156]).

Building on this, in the following chapters of this thesis, we will investigate the usage and suitability of touch and freehand gestures for peripheral interaction and compare their strengths and weaknesses to graspable and tangible user interfaces.

II

Prototyping Peripheral Interaction

Chapter 5

Classification and Perspective

Synopsis

Peripheral interaction is a new research field, which is motivated through the ubiquity of computing technology demanding our attention. By introducing peripheral interaction, interruptions, focus switches and cognitive load shall be reduced. However, peripheral interaction lacks a shared understanding concerning the overall design space. We introduce a classification along six axes consisting of the dimensions explicitness, input, proximity, granularity, privacy and feedback. Furthermore, the primary task may also impact the choice of peripheral interaction style.
Apart from the classification, peripheral interaction can be reviewed from a task-based perspective. The task-based perspective considers the peripheral task as one entity independent from the current interaction style. Peripheral tasks can either be user-driven or system-driven, they can be supportive or additional or consist of retrieving or manipulating data.
The overall focus of this thesis is on manual peripheral interaction for desk-based scenarios. However, many findings from the incorporated projects can be generalized for other scenarios, which we highlight later in Chapter 10.

In the previous chapters we gave an overview of related research areas. We started with human capabilities, which form the basis for peripheral interaction: Divided attention offers us the possibility to split our attentional resources among different tasks to successfully achieve multitasking. Habituation and routines make interactions easier and help to push them to the periphery. Additionally our bodily capabilities, especially our haptic perception including proprioception and spatial memory and the ability to interact bimanually, open up a huge design space for interaction with the physical but also the digital world (Chapter 2). Researchers investigate manifold input strategies. Limiting input to hands and arms, the most prominent examples are graspable respective tangible interaction, touch interaction and freehand interaction (Chapter 3). All three interaction types can be applied to offer eyes-free interaction, thus requiring less or no visual attention. Moreover, microinteractions are designed to reduce time needed to interact with a device or system. Finally, ambient information systems already successfully show that humans are able to perceive information in the periphery of their attention (Chapter 4). Peripheral interaction now takes it one step further and not only tries to offer *perception* in the periphery, but also *active input*.

This chapter offers a classification and a task-based perspective on peripheral interaction, which will be used to define the focus of this thesis.

5.1 Classification of the Design Space

With peripheral interaction being a rather new field, there is no shared understanding of the design space yet. Peripheral interaction could be achieved in many ways, as related fields such as eyes-free interaction or microinteractions imply. However, related projects in the field of peripheral interaction (cf., Chapter 4.4) up to now mainly rely on graspable or tangible user interfaces. Figure 5.1 depicts an approach to classify peripheral interaction more widespread, covering the dimensions explicitness, input, proximity, granularity, privacy, and feedback (loosely based on [103])[1]. Additionally the primary task, which naturally imposes constraints for potential peripheral interactions, is also included.

Explicitness: Explicitness describes the level of active and purposeful user involvement during interaction ranging from explicit to implicit interaction. Explicit interaction describes the conscious involvement of the user with the system [138] while implicit interaction describes interaction that is interpreted as input by the system but not consciously carried out by the user to achieve an input to the system [211]. While implicit interaction can enrich peripheral interaction, usually peripheral interaction is explicit interaction, because the user consciously initiated – often intrinsically motivated – a task (e.g., wanting to skip a song while listening to music).

[1] The here presented classification is a refined version enriched by the knowledge gathered since the previous publication: Hausen, D. and Butz, A. *Extending interaction to the periphery.* In Workshop Embodied Interaction: Theory and Practice in HCI. In conjunction with Human Factors in Computing Systems (CHI), ACM, 2011, 6 pages.

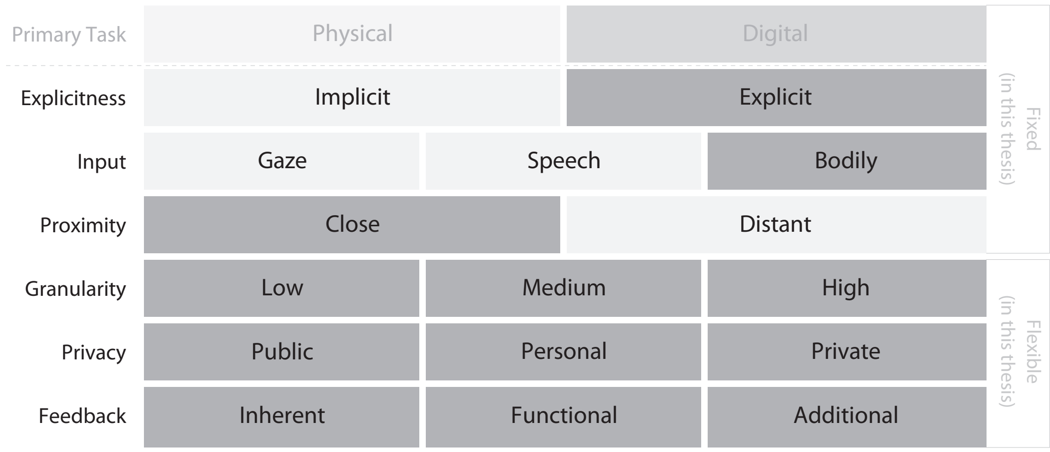

Figure 5.1: Classification for peripheral interaction: Primary task and dimensions of peripheral interaction. Dark grey background denotes dimensions, which are covered by projects in this thesis.

Input: Input to a computer based system is limited to our bodily capabilities and senses. Typical input styles next to mouse and keyboard are based on gaze, speech or bodily input [133]. Bodily input can be further divided into manual input by the hands and arms – which is the most common approach – or other body parts, such as the head (e.g., [39]), feet (e.g., [14]) or any other body part [245]. Manual input usually is achieved by either graspable or tangible interaction, touch or freehand interaction. Of course hybrid approaches are possible (e.g., tangible gesture interaction [237]).

Proximity: Peripheral interaction can be carried out over a variety of distances. Proximity is hugely influenced by the input style. Speech recognition as well as gaze recognition can be performed over a reasonable distance. However, bodily input is usually constrained to the range of our body, hence – especially for manual interaction – at arm's length. One exception are freehand gestures, which could be recognized and tracked from further away. However, this might decrease tracking accuracy, at least with today's sensing technologies.

Granularity: Granularity describes the number of commands that can be encoded. For example glancing or gazing at an object just encodes two levels – looking at it or not looking at it. Of course, through a different design, for example, following a path with the eyes, more commands can be encoded by eye-tracking based systems. Speech input in contrast theoretically can encode an infinite number of commands. Granularity of bodily interaction hugely depends on the design and implementation of a system. For example when relying on casual hand gestures, there are four cardinal directions in which one could wipe. However, more elaborate gestures incorporating for example the orientation of the hand and fingers, can encode much more information. Similarly single as well as multi-stroke gestures for touch interaction increase the granularity [257, 261]. For graspable or tangible devices, granularity depends on the tangible or graspable devices and their characteristics.

Privacy: Privacy of data and input should be considered for peripheral interaction. While traditional input into a computing device with keyboard and mouse is not easily observed, at least when bystanders cannot see the display, peripheral interaction often relies on input mechanisms that are more easily observed. Gesturing in mid-air as well as spoken input are bound to be interpreted by others [202]. On the other hand, microgestures [262] (cf., Chapter 4.2) as well as gaze input is rather hard to observe [62]. Hence, when designing a device, which supports peripheral interaction, one should review whether the data is public (can be disclosed to everybody), personal (not necessary private, but still personal such as the availability in the office) or private (should not be revealed to anybody but the owner) and choose an appropriate interaction style.

Feedback: Feedback can be either inherent, functional or additional/augmented [253]. *Inherent feedback* is defined as "information provided as a natural consequence of making an action. It is feedback arising from the movement itself" [149], thus proprioception (cf., Chapter 2.2.1) gives inherent haptic feedback about for instance the direction of a performed wiping gesture. *Functional feedback* describes feedback that is given by the task itself. Wensveen et al. states that "functional feedback should be viewed in respect to the needs, intentions and desires of the user" [253]. For example when a user wants to skip a song, the song being stopped and the next song being started offers functional audio feedback. *Additional (or augmented) feedback*, is feedback that is not part of the task or the interaction itself, but added to the task or system to assure the user [253]. For example when manipulating a graspable or tangible device, the device could light up to additionally inform the user of the interaction. Of course, both types of feedback – functional as well as additional – can tackle all our senses, for computing devices this usually means the visual, auditory or haptic senses.

Primary Task: The primary task – carried out in the attentional focus – still imposes constraints on the peripheral tasks. Primary tasks can either be physical, implying that no (or hardly any) computerized technology is involved (e.g., teaching a class), or digital, hence the primary task itself is already achieved with the help of computerized systems (e.g., typing a text). Both types of tasks can engage several senses (visual, auditory, haptic) and consequently body parts (e.g., hands while typing, feet while walking). Thus, some peripheral interaction styles might be more fitting than others in certain scenarios.

5.2 Task-Based Perspective

Apart from the presented classification, which should give an overview of the overall design space for peripheral interaction, we extracted a task-based perspective. The task-based perspective considers the peripheral task as an entity independent from the actual execution (i.e., independent of the interaction style). Hence, the task-based perspective gives and overview on the motivation for peripheral interaction, the relation to the primary task and the effect on the digital system. Although this thesis and all projects belonging to it rely on manual peripheral interaction, this perspective can be applied to any other peripheral device.

The task-based perspective includes three categories (see Table 5.1):

User-Driven vs. System-Driven: The users themselves want to interact, hence the interaction is internally motivated (e.g., changing the state of an instant messenger) or the system requires interaction, thus interaction is externally motivated (e.g., reaction to notifications). Similarly multitasking research tasks of external and internal interruptions [176] (c.f., Chapter 2.1.2).

Supportive vs. Additional: The peripheral task is related to the primary task, thus being supportive (e.g., changing tools in a graphics editing program while drawing) or the peripheral task is independent from the primary task, thus being additional (e.g., changing the state of an instant messenger). In relation to supportive tasks, Bakker et al. previously acknowledged that activities can be divided in different sub tasks with only some of them moving to the periphery [22].

Retrieval vs. Manipulation: Content can be just retrieved or acquired (e.g., information about the next upcoming appointment) or content can be manipulated or changed (e.g., deleting an email).

Table 5.1: Projects of this thesis categorized according to the task-based perspective: User-Driven vs. System-Driven, Supportive vs. Additional and Retrieval vs. Manipulation

	User-Driven	**System-Driven**	**Supportive**	**Additional**	**Retrieval**	**Manipulation**
StaTube	✓			✓		✓
Appointment Projection	✓	✓		✓	✓	✓
Music Controller	✓			✓	✓	✓
Interaction Styles & Feedback		✓		✓	✓	✓
Unadorned Desk 2D	✓	✓	✓	✓	✓	✓
Unadorned Desk 3D	✓	✓	✓	✓	✓	✓

StaTube (cf., Chapter 6.1) is designed to manipulate one's Skype state with the help of a graspable interface. Hence motivation to interact with StaTube is user-driven. Usually, instant messaging is not the primary tasks, and even if chatting is the primary task, changing the state is usually not required during a chat. Consequently, the task can be considered as additional task. When manipulating the graspable interface the Skype availability state is changed, thus StaTube offers manipulation of data. The *Appointment Projection* (cf., Chapter 6.2), visualizes upcoming appointments projected onto the user's desk. Users can acquire information about the next upcoming appointment by wiping towards themselves, which is usually a user-driven interaction. Additionally, a reminder animation is shown once an appointment is approaching. This reminder can be stopped by wiping away from the user, which depicts a system-driven interaction, as the reminder was started by the system and the user is "answering" to that. As keeping track of one's upcoming appointments is usually not related to the main task while working on a desk, the Appointment Projection supports an additional task. Data can be retrieved (information about the next appointment) but also manipulated (stopping the reminder). The *Music Controller* (cf., Chapter 7.1) offers interaction to start or stop music, skipping songs and changing the volume. Controlling the music is usually motivated internally and not by the system. It is an additional task while working on the computer and the state of the music player is manipulated (e.g., volume control) or content is retrieved (e.g., a new song). *Interaction Styles & Feedback* (cf., Chapter 7.2) is a lab based exploration, which uses email notifications to trigger interaction. Hence, the interaction is system-driven. The system is designed to offer quick email sorting upon incoming email alongside another task. Thus it is built to support an additional task. As a newly arrived email can just be shown but also for example be deleted, the system offers both, retrieval and manipulation. Both manifestations of the *Unadorned Desk* (cf., Chapter 8) – 2D and 3D – have not been designed for a distinct task but offer storage in off-screen space to position items (e.g., commands, applications, tools). Hence, the Unadorned Desk could be used for all kinds of tasks, thus covering all categories. Imagined applications could be changing tools in a graphics editing program while drawing, storing applications, regularly used commands or features for controlling applications such as the music player or instant messaging clients in the off-screen space. All projects will be described in more detail in the following three chapters.

5.3 Focus of this Thesis

This chapter offered a classification for peripheral interaction and a task-based perspective. They both show that the field of peripheral interaction can be addressed in many different ways. However, covering the whole design space is not possible in one dissertation, hence we had to narrow down the scope of our research.

The highlighted area in Figure 5.1 depicts the focus as well as Table 5.1. Based on the chosen application area – desk based scenarios – the primary task involves working on a regular computer, which engages the visual channel (through the computer display), the haptic channel (through mouse and keyboard) and potentially the auditory channel (for example through auditory feedback). Choosing a desk based and office work based scenario offers several practical advantages such as the connection to the computer for wired communication and power supply for prototypical implementations. However, the desk and the office in general is a place of many interruptions and many parallel tasks [85], hence it seems very suitable for the introduction of peripheral interaction.

As already stated previously, peripheral interaction is designed to be carried out explicitly (although it might be enriched with implicit interaction). Hence we focused on explicit manual interaction. Focusing on manual interaction makes sense for several reasons. As found by Bakker et al., (1) peripheral interaction in our physical daily life also mostly relies on bodily interactions carried out with the hands [22]. Additionally, (2) motor movements are considered to be the least difficult form of interaction [209] and are (3) well suited to become habituated [255]. We believe that other input styles depicted in the classification are also fit for peripheral interaction, however, in this early phase of peripheral interaction research, we consider it suitable to start with the most established ones to investigate basic principles of peripheral interaction. Based on the chosen input styles, input is close by for all prototypes, while granularity ranges from low to high depending on the project itself. Concerning data that is used during the peripheral tasks, our projects mostly deal with personal data, but – especially in case of the Unadorned Desk – other data types are possible. Feedback differs between projects. StaTube and Interaction Styles & Feedback both offer additional feedback while the Appointment Projection and the Music Controller rely solely on functional feedback. The Unadorned Desk 2D investigates several on-screen feedback designs compared to no feedback, while the Unadorned Desk 3D again omits additional feedback.

In Chapter 10, we will extract the findings from these six prototypes, which can be generalized for other use cases and potentially also other input styles concerning peripheral interaction.

Chapter 6

Basic Explorations

Synopsis

This chapter introduces two basic explorations: StaTube, in reference to related work, takes up the idea to use a graspable device for peripheral interaction. A tube shaped object, located on the desk, displays the state of selected instant messaging contacts in a color coded way. Additionally the own state is displayed and can be manipulated by turning the upmost level. In an in-situ deployment we found that participants made extensive use of the shortcut provided by StaTube for setting their state, which increased their state accuracy. StaTube's physicality helped to integrate it into the participants' daily work flow.
The Appointment Projection digs into a new interaction style – freehand interaction. Calendar appointments are projected onto the desk in a spiral visualization, which can also pulsate to remind about a close by appointment. By wiping towards oneself, one can acquire additional information (exact time, location, etc.) about the next appointment. By wiping away from oneself, a pulsating reminder animation can be stopped. Although we increased the number of interactions required to access detailed information (compared to a traditional reminder pop-up) we decreased loss of productivity and errors in the primary task. Thus, we consider that a first step towards applying a new interaction style to peripheral interaction.

As related work shows (cf., Chapter 4.4), it is common to rely on graspable or tangible interfaces to offer peripheral interaction. We built on this and explore a graspable device – StaTube – to gather first insights on peripheral interaction and its characteristics. Subsequently, inspired by related fields, such as eyes-free interaction, we investigate peripheral interaction further by looking into freehand gestures with the Appointment Projection. Both projects combine peripheral interaction and ambient information (cf., Chapter 4.3).

The following chapter introduces two basic explorations – StaTube in Chapter 6.1 and Appointment Projection in Chapter 6.2 – their design process and their evaluation. From both projects we derive several findings, which can be generalized beyond these specific projects.

6.1 Exploration: StaTube

StaTube[1] [101] combines ambient information and peripheral interaction. StaTube is designed to offer immediate access to the user's instant messaging (IM) state by turning its upmost level. The graspable device (see Figure 6.1) shows the user's own instant messaging state as well as the states of selected contacts[2]. Keeping the state of the instant messaging client up to date is an often neglected task as it is considered to be too cumbersome, although people are interested in an up to date state of their contacts, as a survey revealed (cf., Chapter 6.1.2). Thus, supporting this task in the periphery seems to be of value to users.

StaTube is built based on an online survey, which investigated instant messaging usage and afterwards evaluated in a two week in-situ deployment with six participants.

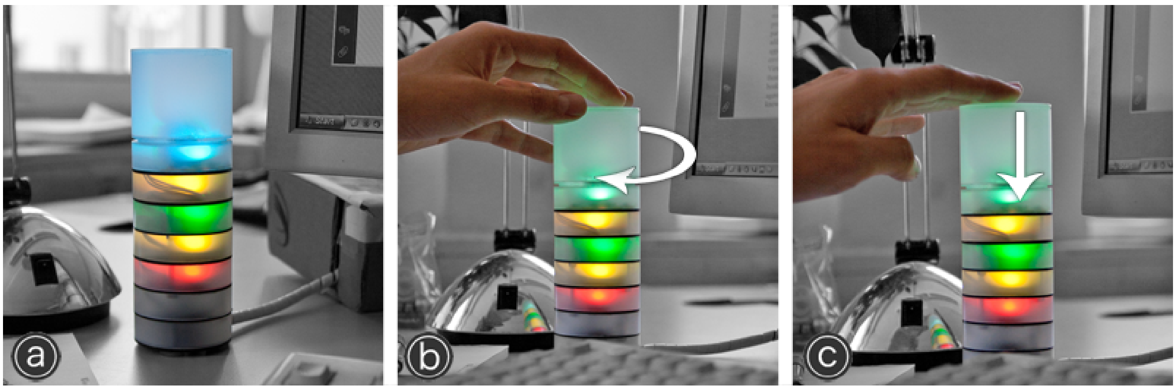

Figure 6.1: StaTube is a graspable device on the user's desk. The upmost level represents the user's own state while the other levels show selected contacts (a). By turning the upmost level the state can be changed (b). Pushing down the upmost level activates a timer (c).

[1] Chapter 6.1 is based on: Hausen, D., Boring, S., Lueling, C., Rodestock, S., and Butz, A. *StaTube: Facilitating State Management in Instant Messaging Systems.* In Tangible, Embedded and Embodied Interaction (TEI), ACM, 2012, 283–290.

[2] The video figure illustrates StaTube: http://youtu.be/5f1tsIrUHTA (Last Accessed: 02.10.2013)

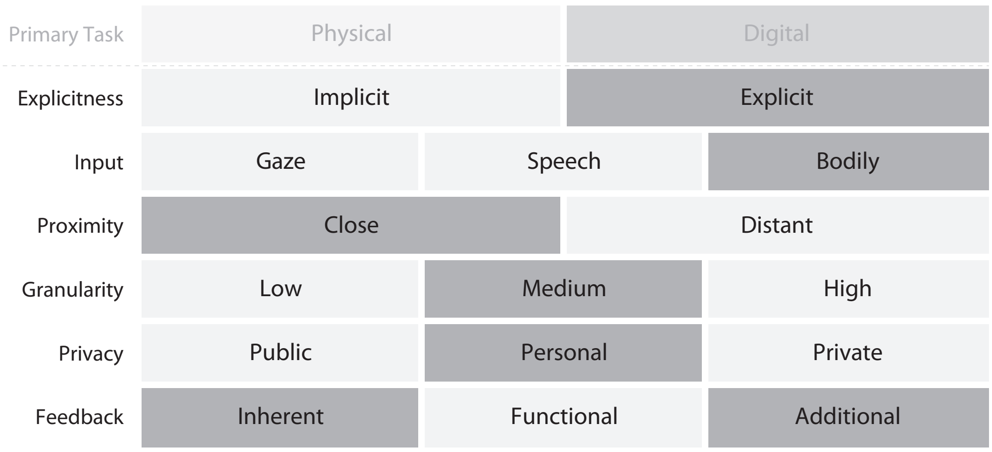

Figure 6.2: StaTube located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by StaTube.

StaTube in the Design Space

In reference to the previously spanned classification (cf., Chapter 5.1), Figure 6.2 depicts, which areas are covered by StaTube. StaTube is connected to a regular computer to communicate with Skype. Hence, the primary task is usually also computer-based. Interaction is explicit with the help of the hands through a graspable user interface. Hence interaction is close by. Granularity is medium as the number of available states in instant messaging clients is usually limited. However, StaTube offers more than the standard set of states (cf., Chapter 6.1.3). Privacy can be ranked as personal as the data is already available through the instant messaging client to contacts, however, it is information that is not publicly available. Based on the manual interaction style, inherent feedback is provided through proprioception. Furthermore while turning StaTube one can feel each state snap haptically. Moreover the StaTube gives additional feedback through colored light for the users themselves but also for passing by colleagues. In addition to this, the instant messenger itself might provide cues on the computer's display through changing the color of for instance an icon.

In terms of the task-based perspective (cf., Chapter 5.2), setting the state is usually internally triggered and thus user-driven. It is carried out alongside other, unrelated tasks and hence can be considered as additional task. Users do not acquire information or data but actively manipulate data respectively their availability state.

6.1.1 Background: Instant Messaging and Presence Information

With colleagues being spread between different office buildings, cities or even countries, instant messaging has established itself as one further means of communication during work. Additionally, to gather some kind of awareness for remote located colleagues, different (ambient) systems have been developed, which show the availability of colleagues. With StaTube being designed and evaluated in the office context, this chapter gives a short introduction on related work concerning instant messaging and presence information in the context of office based work.

Instant Messaging at the Workplace

Many studies investigate the general usage of instant messaging such as the frequency and quantity of messages [82, 146]. Generally instant messaging fulfills four core functions in the personal context as well as in the office context: "short questions and clarifications, coordination and scheduling, arranging impromptu social meetings, and keeping in touch with friends and family" [181]. Other researchers only distinguish between two user groups. One group, which only uses it for short inquiries, while the other group carries out elaborate and long talks [128]. Instant messaging is often discussed in the context of multitasking and interruptions [92]. Based on Czerwinksi et al.'s [59] interruption severity levels, notifications, which usually are turned on for all messages received through instant messaging, are considered to be most disruptive. However, instant messaging can also be used to manage interruptions by receiving task-related information or quickly negotiating availability [80]. Many people also started to use instant messaging because – in contrast to for instance the telephone – it offers the possibility to postpone answering and one can indicate one's availability [112]. However, as we will show in Chapter 6.1.2, the state is often not updated and hence less effective.

Presence Information

Displaying presence information is often done in an ambient way through displays (e.g., [123, 182]) or physical objects (e.g., [86, 173]). Information capacity differs between different projects, with most systems just stating whether a person is present or not but some also incorporating information about the whereabouts [215]. Additionally different mappings are explored such as distance between contacts or rotational speed to display idle time [234]. *Online Enlightenment* [228] displays all colleagues and whether they are at their desks based on the spatial layout of the office instead of a list as common for instant messaging clients. *Portholes* [66] use video data to display the presence state at the desk. All these systems are designed to offer awareness about other people's availability or presence state. Many of these systems rely on implicit interaction collected by sensors [75]. This takes the burden of keeping the state up to date from the users, however, it also reduces the autonomy of the users. One contrasting example are the tangible objects with embedded displays by Holleis et al. [117], which can be turned to convey a different state. By moving the task of updating the state information into the periphery we hope to preserve the users' autonomy but also reduce the effort and disruption of keeping the state up to date.

6.1.2 Survey: Current Usage of Instant Messaging

Before building StaTube we conducted an online questionnaire to assess benefits and drawbacks of instant messaging usage to address user needs best with our design. The survey contained 36 questions and was divided in three parts: (1) IM usage in general, (2) IM usage at work, and (3) ideas towards a physical device enhancing IM usage. We used free text answers and 5-point Likert scales (1 = I totally disagree; 5 = I totally agree).

Participants

We collected 46 responses (25 female) ranging in age from 21 to 55 (average age was 29). Nearly all of them work full or half time (44 participants) and use a computer with internet access at work. Nearly half of the collaborating colleagues (43.5%) are located at remote offices. A majority of participants use instant messaging often or even always while on their computer (*median* = 4) (cf., Figure 6.3). 39% of all participants, who generally use IM, also use it at work. Mostly instant messaging is used for one-to-one chats (61%), but group chats are also common (39%). Only some clients support audio or video chats (used by 10%).

States

All IM clients that are used by our participants support different states. The most used state is *available* (63%), followed by *away* (48%), *invisible* (41%), and *do not disturb* (22%) (multiple answers were allowed). Most stated reasons for changing the state are leaving the desk (here state change is often performed automatically by the IM client after a predefined idle time) or not wanting to be disturbed. However, 25% of all participants never change their IM state. Many clients offer an additional text area – called mood message – which can be freely filled by users. Most of our participants never or only sometimes use this option (*median* = 2) (cf., Figure 6.3). In contrast the state information of colleagues is checked regularly (*median* = 3) (cf., Figure 6.3), especially before contacting a colleague (56% of all cases).

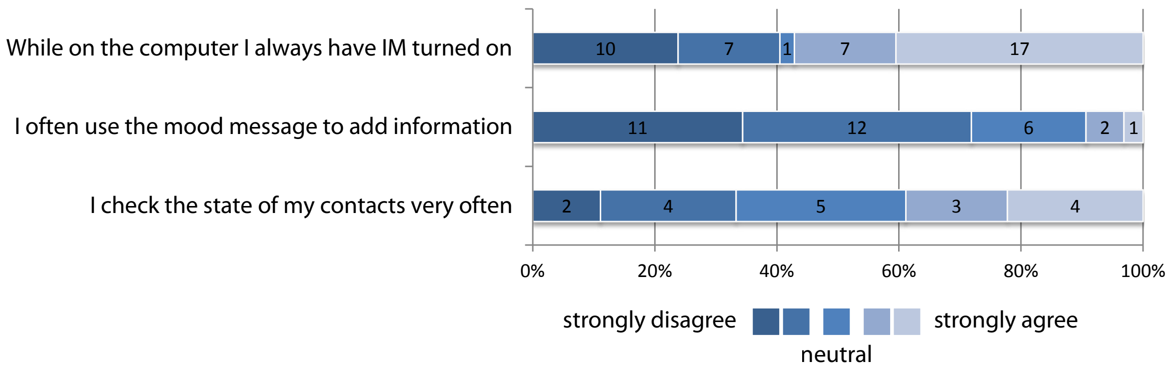

Figure 6.3: Likert scale ratings of the survey participants concerning their instant messaging (IM) usage.

Disturbances

Asked about disturbances, 33% of all participants stated to be regularly or often disturbed by chat messages. This is especially true when their thoughts are disrupted by unrelated messages (43%). Additionally chatty messages assuming an always availability while at work are considered disrupting (21%). Moreover, independent from the message's content, the blinking in the task bar already disrupts some participants (14%). Audio notifications are often turned off, as they were perceived to be even more disruptive than visual cues and are often also not suitable at the work context with other colleagues working in the same room.

Possible Extensions to Instant Messaging

Extensions that have been envisioned by our participants include more detailed states for regular occurrences such as being in a meeting or out for lunch. Concerning a physical representation participants requested a diverse number of contacts being displayed ranging between 1 and 100 (*median* = 5; *mean* = 10). Regarding changing one's own state, answers again were diverse suggesting buttons, touchscreens, sliders and – mentioned by most – turning an object. Envisioned shapes included cubes, small displays but also extravagant ideas such as flowers with a leaf for each contact or a traffic light for each contact.

6.1.3 Designing and Building StaTube

With the results of the survey and our goal of offering a peripheral device we set out to design a physical object connected to an instant messaging client. This chapter first summarizes the design requirements uncovered by the survey, afterwards the final design will be described.

Design Requirements

From the survey we derived three design requirements: (1) ambient information about contacts' states, (2) more direct access to state updates and (3) extension of standard IM features.

Ambient Information about Contacts' States: We found that people usually check the online state before contacting a colleague. Ambient information can help to minimize disruption while checking the availability of the desired colleagues. Users do not have to switch to their IM client and search a list of contacts to find out that the colleague is not online or states to not want to be disturbed. Instead they can just glance at the physical object to obtain this information. They might even realize changes in the periphery while focusing their attention on the computer's display and their current primary task. We opted for visual cues through colors and light, because audio was considered to be more disturbing by our survey participants and especially to not be suitable in the office context as colleagues with close by desks might be disturbed. Additionally, IM clients already use color mappings for state information (e.g., yellow for *away* or red for *do not disturb*). Hence, IM users do not need to learn another mapping but are already familiar with it.

More Direct Access to State Updates: The survey results already showed that participants are interested in the state of their colleagues. However, they themselves do not keep their state up to date. 25% actually never update their state. To overcome this controversy, we want to offer a more direct access to one's state. Instead of clicking on small icons and switching windows and hence losing focus of the primary task we decided to use a physical object, which can be manipulated by the hands at best in the attentional and visual periphery.

Extension of Standard IM Features: To give more elaborate information to their contacts, participants stated that they would like to give more detailed information about their state. Especially *away* does not give any clue about the duration of absence. However, more detailed information such as "out for lunch" or "in a meeting" could give colleagues a clue about the approximate return. The mood message could already be used for such information, but explicitly putting in this information every time one leaves the desk is rather cumbersome and hence the mood message is currently only used rarely. Offering additional states and information about the approximate duration in an easy accessible way is the third goal of our design.

The Final Design

With these three requirements in mind we had to decide on a shape. Suggestions by the survey participants very diverse. We finally decided on a tube shaped object for four reasons: (1) A tube offers – at least in theory – an infinite number of stacked levels to represent contacts' states. (2) These levels can be viewed equally well from every direction. Thus orientation of the tube or the user towards the tube does not matter. This not only makes the tube usable for the owner but also for people passing by, who might see an empty desk but based on the color of the users own level (the topmost level, which will also be used for interaction) can get additional information about the absence. (3) The tube – or its topmost level – can easily be rotated from every direction. Thus the orientation of the object is also not relevant for interaction, increasing the chance of state changes being performable in the periphery. (4) Additionally, turning the tube can encode an arbitrary number of states, while for instance a cube shaped object would be limited to six sides and hence six states.

To explore the best diameter for easy rotation, we built four paper based prototypes with different diameters (inspired by [256]) – 4 cm, 5 cm, 6.5 cm and 8 cm – and informally asked five potential users to rotate them with one hand on their desk and state which one they preferred. Three of the participants chose the diameter of 5 cm while the other two chose 6.5 cm. As we observed, tubes with a smaller diameter more easily toppled, we chose a diameter in between the two selected ones and built our tube with a diameter of 6 cm.

The shape and the colored light resembles the design of *Lantern* by Alavi et al. [3]. While Lantern is designed for a different use case – class orchestration – the design already showed that it can increase awareness and hence productivity. This also verified our design decisions.

Implementation

The final implemented prototype (see Figure 6.4) consisted of the tube shaped physical object and the software connecting the tube to an instant messaging client.

Hardware: The tube consists of frosted acrylic glass to hide the internal electronics but show the colored light. Each layer is equipped with two RGB LEDs (Multicomp SMD OVS-5309). We used black plates to separate layers and prevent light leaking to other levels. The topmost and largest layer which represents the user's own state is additionally equipped with a rotary encoder (Panasonic EVE-QDBRL416B), which can be turned (to select a state). Besides the regular states *online* (green), *away* (yellow), *do not disturb* (red) and *invisible* (white) and *offline* (no light) we added the following additional states: *on the phone* (blue), *cannot answer* (turquoise), *eating* (pink) and *in a meeting* (violet). We used colors mixed with red for states indicating potential longer absences (i.e., pink = eating and violet = in a meeting). In contrast for potentially shorter absences we used blueish colors (i.e., blue = on the phone, and turquoise = cannot answer). As these states are not natively supported by Skype, they are all mapped to *away* in the instant messaging client. The additional information is presented as mood message so it is also available to people who are not equipped with StaTube. Users with StaTube, however, see the level representing the respective colleague in the appropriate color.
To give more detailed information about the expected duration of a state we integrated a timer. By pushing the upmost level the timer is set according to the interval that was predefined by the user in the settings dialog. Repetitive pushing down the upmost level adds the timer interval to the already stated time. For users equipped with StaTube, the elapsed time is visualized by dimming the light. The remaining time is also added to the mood message.
Due to technical limitations, we only offer four contact levels being lit (the lowest level

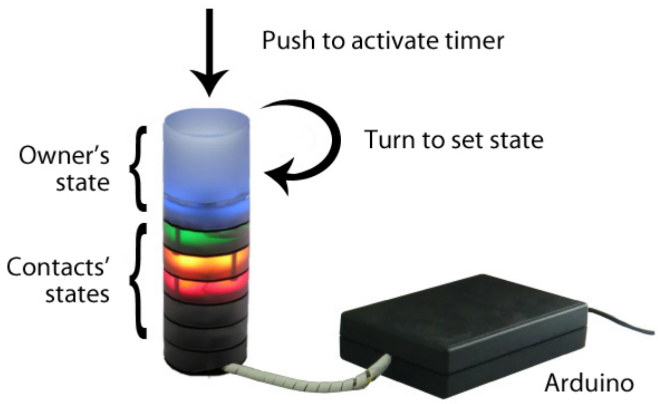

Figure 6.4: The prototype of StaTube. The upmost level represents the owner's state while the lower levels represent the contacts' states. By pushing down the upmost level a timer is set. By turning the upmost level the state can be changed. The black box carries the Arduino, which controls the prototype.

contains all wires). However, by adding more LED drivers more levels could be added to the prototype. The current prototype is controlled by an Arduino Duemilanove and an LED driver (TLC5940). The object communicates with the instant messaging client via USB. Additionally USB also offers power supply to the tube.

Software: The software is implemented in Java and takes care of the communication of the object and the instant messaging client. This prototypical implementation is connected to Skype (which was the most used IM client in our survey) via Skype4Java[3]. When installing the tube for the first time, the user has to select the serial port, which has been used to plug in the prototype. Additionally, the user has to approve that Skype is being accessed by an external application. A GUI is provided to link the levels to selected contacts. Additionally the timer interval for one push can be defined there.

6.1.4 Procedure of the In-Situ Deployment

StaTube is designed to reduce instant messenger disruptions while working. To evaluate its drawbacks and benefits we opted for an in-situ deployment and recruited participants who collaborate with remote located colleagues via instant messaging. Having the prototype at their regular desk for an extended period of time will also give us insights on the integration into routines and if and to what extent the interaction could shift to the periphery.

Participants

To evaluate at least two participants together, who are both equipped with the StaTube, we built two identical objects. Hence, for every exploration we selected two office workers, who collaborate but do not sit in immediate vicinity. We recruited 6 participants grouped in three pairs (always one male and female colleague). They ranged in age from 26 to 30 (average age was 28). Two pairs were located at different floors in the same building, while one pair was working from different places (one from the office and one from home). All of our participants already used Skype in their daily routine to communicate with each other. None of the participants took part in the previous survey and none of them reported color-blindness, which might have interfered with our color coding.

Additionally an online survey was handed out to contacts of our participants after they used StaTube, which was answered by 13 people (6 female). They ranged in age from 23 to 39 (average age 30). Nearly all (92%) also use Skype at work, 85% of them daily. All of them have been in frequent contact with the colleague who tested StaTube (*median* = 4 on a 5-point Likert scale). At least one contact of each participant filled in the questionnaire.

[3] http://blogs.skype.com/2006/10/26/skype4java-a-developers-collab/ (Last Accessed: 19.06.2013)

Procedure

Each exploration lasted for three weeks, which included a two weeks deployment of StaTube at every participant's desk. To capture as much information about the experience while using StaTube we used automatic logging and three semi-structured interviews. Additionally, we provided all participants with a web-based contact form, which we instructed them to use whenever questions arose or they had any thoughts on using StaTube that they were happy to share with us.

Baseline – without StaTube: During the first meeting we carried out a first semi-structured interview collecting data about our participants' usual Skype behavior. Afterwards we installed a logging tool and asked participants to not close it during the week. We collected *if* and *when* messages (chat or call) were exchanged, *who* initiated the conversation and in case of group chats *who took part*. Additionally, we saved all *states*, *state changes* and *mood messages* for all participants and all their contacts. To ensure privacy all contact names were encrypted as MD5 hashes. Hence we were able to identify each contact throughout the whole evaluation but we did not know their identity. An icon in the system tray informed the participants that the logging software was running.

Week 1 – with StaTube: After one week we returned and installed StaTube at the users' desks (cf., Figure 6.5). We gave them a short introduction about the features of StaTube and how to interact with it. They were free to place StaTube wherever they liked on their desk. After they familiarized themselves with StaTube we handed them the link to the blank web form to easily send anything that was on their mind concerning StaTube to us. To get more insights into the usage of StaTube we extended logging and also recorded *which contacts are assigned to StaTube*, *timer usage* and whether *states were changed via Skype or StaTube*.

Week 2 – with StaTube: At the beginning of the second week, we conducted a second semi-structured interview to find out about their experiences with StaTube and if they realized any effects on their Skype usage. Having conducted the interview, we left the participants alone with StaTube for another week. One week later we returned again to carry out a final semi-structured interview to capture if their experience changed. We uninstalled StaTube and handed the participants a link to a questionnaire and asked them to pass it on to their Skype contacts. We aimed at finding out whether contacts of our participants perceived any change of behavior.

6.1.5 Results of the In-Situ Deployment

This chapter summarizes our results concerning general Skype usage and Skype usage with StaTube. We especially assess whether we were able to integrate StaTube as peripheral device. Again when applicable we used a 5-point Likert scale ranging from 1 = I totally disagree to 5 = I totally agree.

Figure 6.5: StaTube at two participants' desks.

Skype Usage without StaTube

We included one week of logging all interactions with Skype as baseline for comparison to Skype usage with StaTube. Additionally we use this data to verify if our participants are a good fit compared to the users from our survey.

General Skype Usage: All our participants use Skype daily at work. Only one person closes it rarely when working very concentrated. Additionally five participants also use Skype during their free time. Mainly they use Skype for text chats and hardly any audio or video chats. Hence they all rate their Skype usage as pretty frequent (*median* = 4). On average they receive or send a message every 10.2 minutes. Most of these messages are short inquiries but some of them turn into longer conversations, mostly closely related to work. However, one participant also receives many private messages, as she is working from home and hence does not have clearly defined working hours. All participants are also involved in group chats, which are responsible for 26% of all messages.

Own State: Our participants are divided in two groups concerning their frequency of state updates. While two consider their state to be fairly accurate using regularly all available Skype states, the majority of our participants consider the accuracy of their state as low (overall *median* = 1.5; cf., survey: *median* = 2) because setting the state is considered to be an additional task that is often forgotten. Logging revealed that half of our participants never changed their state during the week we logged all their interactions (cf., survey: 25%). For our participants with a fairly accurate state, time between two state changes is on average 87 minutes, while those who stated that their state is rather inaccurate take 940 minutes on average to change their state. These numbers include the automatic *away*, which is set by Skype after a certain time without any interactions with the computer.
Our participants stated that they feel that their contacts do not respect their state and contact them anyhow, which annoys them. However, our participants themselves contact others independent of their state, as they feel they can answer when they are back at their desk

or have time for it. Interpretation of states also differs among participants. Some consider *away* as being away from the desk, others interpret it as "I do not want to chat right now". To minimize disruptions, some participants use *do not disturb* while others prefer *invisible*. States are changed through the Skype window but also through the system tray icon. Mood messages are rarely used (*median* = 1.5; cf., survey: *median* = 2). If they are used they contain information about the current location or random personal messages but are usually not related to the current activity or task.

Contacts' States: Five of our participants usually have Skype minimized in the taskbar or system tray. However, to observe or check the contacts' availability state, the Skype window has to be in the foreground. Explicitly switching to the window is considered to be cumbersome and disruptive by half of our participants. An alternative are pop-up messages, which inform about contacts going *online* or *offline*. Five participants have turned them on. However, two of our participants are rather annoyed while other two hardly notice them. In general, as these pop-ups are only displayed briefly, they can be easily missed. Audio notifications are often used at home, but are considered to be too disturbing at work, especially for co-workers. Five participants are interested in the state of their contacts, but are annoyed that they are often incorrect (e.g., when a contact who is listed as *online* does not answer). They do not feel well informed about their contacts' availability and do not trust their state (both: *median* = 2).

The behavior that we observed is similar to our survey results. Hence we consider our selection of participants a good fit for the study.

Skype Usage with StaTube

In the following we report on the data that we collected during the two weeks with StaTube and compare it to the data that we collected during the baseline week.

General Skype Usage: Our participants had StaTube connected for 74 hours during the two weeks. This is 92% of the average 80 working hours during these two weeks. During the second week three participants occasionally forgot to turn on StaTube, additionally three had a very busy week and hence partly abandoned Skype. Furthermore, we observed that the novelty effect began to fade. One participants stated that the *"play instinct"* decreased during the second week. Another participant stated, that *"the system wasn't that present anymore (...), it was better integrated in my daily workflow"*.

Own State: Before being equipped with StaTube participants changed their state on average every 655 minutes. During the first week with StaTube the frequency increased to every 90 minutes on average. However, during the second week the frequency again decreased to 368 minutes on average. This might be attributed to the dying novelty effect but also the three participants having a stressful week. Of all these state changes, 92% have been carried out using StaTube instead of the traditional GUI or system tray icon. The increase

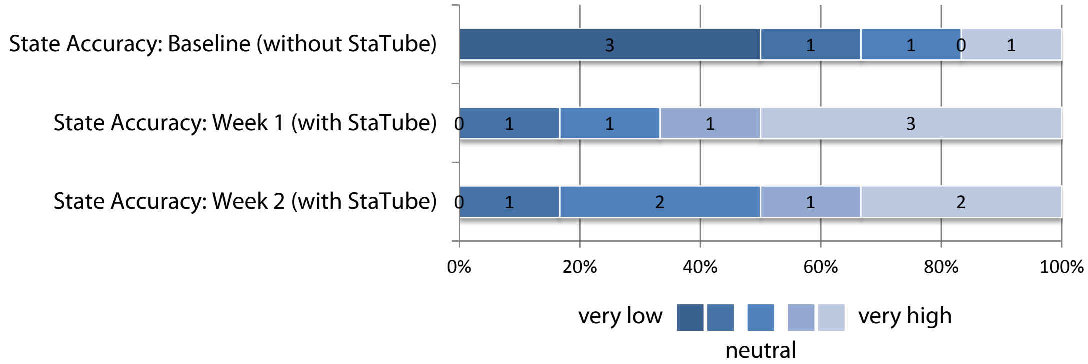

Figure 6.6: Subjectively perceived state accuracy during the baseline week and week one and week two with StaTube.

of state changes was also noticeable in the subjectively perceived accuracy of state information. During the first week participants considered their state to be accurate nearly all of the time (*median* = 4.5). This slightly decreased again in the second week (*median* = 3.5) but it was still much more accurate than during the baseline week (*median* = 1.5) (cf., Figure 6.6). When asked why they increased their update frequency, participants stated that it is faster and easier with StaTube than with the regularly GUI. Additionally, the physical object also acted as reminder for them, or as one participant put it: *"...because it is physical, it is better integrated in the 'leaving-the-desk-flow', when I leave I also lock the door, which is also physical"*. Turning the device in the beginning needed focus during the interaction. However, four participants felt that it became much easier during the second week. From our participants' contacts, 30% who answered the questionnaire stated that they recognized the more frequent state changes, and 75% of them considered the state now to be more reliable and reflecting the actual state.

Contacts' States: Four participants enjoyed that they could see the states of their most important contacts at a glance. The other two beforehand also never used the Skype window to check for their contacts' states. Hence it seems that StaTube adds value for those users who also beforehand were interested in the state of their contacts. Generally five participants felt more aware of the state of their contacts, especially distinguishing between a contact being available through Skype or being offline (lights on vs. lights off), which were 77% of all displayed switches. The visualization truly was ambient as only one person (working late at night with changing light conditions) perceived the changes when being fully concentrated. However, three noticed them when not being very focused. As participants were free to place the object at their own liking, distances from the primary monitor, which might be the center of visual attention in most cases, ranged from 10 to 50 centimeter. However, we did not find any correlation between distance and notification. Two participants told us that they were encouraged by such a switch (lights turning on) to start a conversation. Log data revealed that nine times a person was contacted in the first two minutes after coming online. Only one of these initial messages was sent during the week without StaTube. On average our participants contacted five different people per week with three of them being displayed on the tube. On average 62% of all contacts that they interacted with were displayed on their StaTube. They also stated that they were overall happy with the number of people being displayed there.

Additional States: Nearly every fourth state change (24%) was a switch to one of the additional states (38% eating, 29% in a meeting, 25% on the phone, and 8% cannot answer). Participants needed some time to get used to the color mappings, however after two weeks all of them stated to remember those that they considered valuable and hence regularly used. Contacts of our participants who realized the additional information provided as mood message stated to like that this additional information hints at the approximate duration (even when no timer was used).

Timer: The timer was only used very rarely. We only logged nine timer activations throughout the two weeks participants were using StaTube. Set timer intervals ranged from 10 to 90 minutes (average 30 minutes). Participants stated several reasons for not using the timer. For instances they just forgot about it. Moreover one person worked from home and hence did not attend any meetings but was always at her desk while Skype was turned on. Last but not least participants considered it to be too cumbersome, as it was considered to be hard to estimate the length of an absence. We could also verify this from the log data. The actual time of return (we counted the next state change as return) and the estimated return differed on average more than 25%. The change of brightness that visualized the timer was not perceived by the participants. However it is likely that they were not at their desk during these rare timer activations. Three contacts of our participants noticed the timer and appreciated the information.

Physical Representation: Concerning the physical representation, distinguishing layers was sometimes hard for our participants. With turned on lights, the black plates separating the layers were often not noticeable enough. One participant attached sticky notes to the layers to better remember, which layer corresponds to which contact. Other participants only had problems remembering the mapping if they recently changed the assigned contacts. Overall StaTube was considered to be appealing (*median* = 4). Participants only criticized the rather big black box carrying the Arduino, but not the concept itself.

Social Aspects: StaTube not only affected the participants' Skype communication but also their impression towards their colleagues. One generally felt closer to the colleagues, who were displayed on the StaTube. Another one pointed out that he enjoyed to observe *"the office coming alive"*. One other participant refrained from calling a colleague on the regular phone as he saw that the colleague was offline. Hence, StaTube might also reduce unsuccessful attempts of communication through other channels. Moreover, other colleagues in the office were also interested in StaTube. One colleague started to mimic the additional states by typing the corresponding text into the mood message. As StaTube just parses these messages and displays the appropriate color if the fitting text was found, StaTube lit up in the color although the colleague did not have a StaTube himself. However, although StaTube was glowing red indicating *do not disturb*, passing by colleagues did not refrain from interrupting the StaTube's owner. Nevertheless, this might change if everybody in an office would be equipped with StaTube and hence be familiar with the concept and be able to interpret it.

6.1.6 Lessons Learned

The previous chapter stated a lot of findings concerning the usage and habits referring to Skype or more generally instant messaging. In this chapter, we will summarize how these findings can be generalized to peripheral interaction with graspable devices.

Summary and Limitations

Overall, we were able to increase awareness about the states of important contacts without requiring users to actively focus on monitoring their contacts' states. By offering a physical device we simplified state maintenance and hence were able to improve state accuracy. Moreover we extended Skype and introduced new features which were – at least partly (i.e., the additional states) – well adopted.

However, this work of course also comes with limitations. We only had a small sample of users, hence our results can only be considered as a first exploration. Although we saw the novelty effect wear off we cannot completely rule it out after this two week long exploration. We tested in a real life setting, which gives more realistic insights than lab evaluations could provide, however, of course we were not in control of external events (such as three of our participants having one very hectic week during the exploration). Additionally some events, which might have triggered interesting results (e.g., more intensive usage of *do not disturb* to observe the reaction of contacts on that) just did not occur. Last but not least, instant messaging is a use case, which relies on collective adoption. Without a critical mass of users, some traits just might not develop or show [47]. For instance, even if our participants had more accurate states, all other contacts did not. Hence, it is very likely that their more accurate state is still not considered accurate by their contacts as they are just too used to inaccurate state information.

Generalizable Findings for Peripheral Interaction

StaTube supports instant messaging. However, instant messaging is merely a use case, to give participants a task that is already integrated into their work life to explore our prototype in a real life context. We here summarize and generalize the findings gathered during this exploration.

Shortcut: Setting the state in an instant messaging client is an additional side task that is often neglected because it is considered to be too cumbersome. Hence, peripheral interaction can be utilized as shortcut, simplifying access to functionality, a command or information.

Participants stated that changing the state with StaTube is easier and faster than the traditional way through GUI or system tray icon. Offering this shortcut might not only simplify interaction, but also lead to otherwise neglected interactions being finally carried out.

Enhancement: We used the physical device to enhance instant messaging. We offered additional states (successful) and a timer (less successful), hence peripheral devices can introduce new functionality. All this information could have been inputted before, but even more cumbersome than just a state change. With StaTube additional states were as easy to input as any other regular state.

Action vs. Task: Concerning previous mentioned enhancements, the timer however was not successful. The biggest problem was, that setting the timer requested more thinking. Users are aware of their general state (e.g., just heading off to a meeting), however the duration of a task is often not immediately obvious or not known at all. Hence, even though the action itself – pressing down the upmost level – was very easy, the cognitive processes connected with it were not. Consequently, it is not only the action that needs to be rather easy (while easy has to be understood in reference to training and skill as discussed in Chapter 2.1.3) to move to the periphery, but also the task behind carried out by this action.

Habituation: As anticipated (and discussed in Chapter 2.1.3) habituation plays a big role for peripheral interaction. Interacting with StaTube seems to integrate well in the routines (e.g., one participant stating that it is now just part of his 'leaving the desk workflow') and hence might over a longer period of time actually become habituated. The physicality of StaTube and it being a dedicated device was very beneficial to achieve that. Especially as setting the state still was accessible while probably already locking the computer for leaving the desk and grasping the keys to lock the door.

Learning: We furthermore saw that a learning period is needed for the interaction to shift to the periphery. While the interaction itself is pretty simple – grasping and turning the upmost level – participants still had to focus on this interaction in the beginning. When rotating, one could feel each state haptically snapping. However, states were arranged in an imagined circle and the order of states had to be learned (or observed by the changing light). During the second week most of our participants perceived it to be already much easier and out of their focus to some extent.

Reminder: StaTube increased the number of state updates remarkably. This not only is due to the easier access. Updating one's instant messaging state can be considered as an unannounced task, which relies on prospective memory [255]. The physicality of StaTube hence supported the task just by acting as a reminder to carry out the task more frequently.

Further Benefits: Apart from the previous mentioned benefits that can be achieved by offering peripheral interaction, by making tasks more accessible, additional applications can make use of the available information. For example for the use case of instant messaging, these now up to date state information can be used to show notifications (which are not urgent and can be postponed) at more suitable times to greatly reduce interruptions [58].

6.2 Exploration: Appointment Projection

The Appointment Projection – similar to StaTube – combines ambient information and peripheral interaction. However, the Appointment Projection (see Figure 6.7) is the first prototype in the scope of peripheral interaction, which makes use of freehand gestures[4]. The Appointment Projection is designed to increase awareness about upcoming appointments and to more easily access information about them. Additionally it incorporates ambient reminder animations in case of an approaching appointment to reduce disruption by reminder pop-ups, which are common for most digital calendar applications.

The Appointment Projection was designed based on an initial study, which made use of paper mock-ups. Subsequently, to refine the design we conducted a dual-task lab study and finally assessed the prototype in a two week in-situ deployment with three participants.

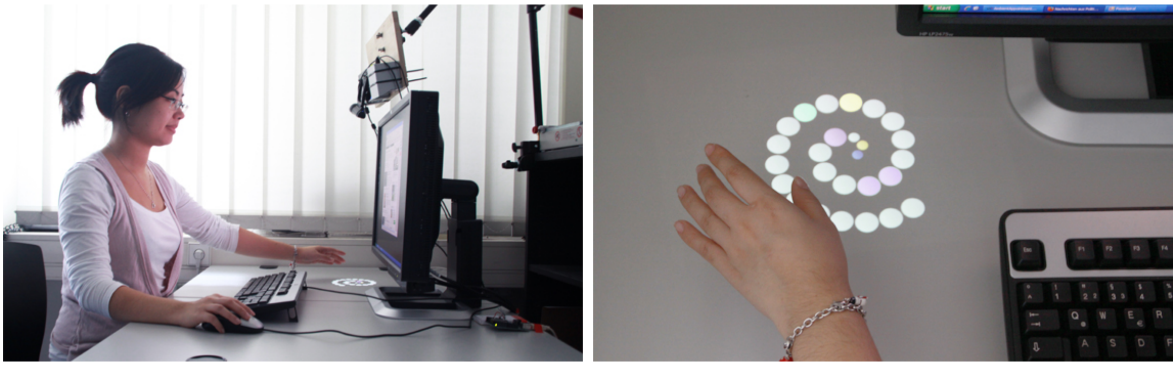

Figure 6.7: User interacting with the Appointment Projection. Wiping towards the user offers details about the next appointment as balloon pop-up on the screen. Wiping away silences a pulsating reminder animation.

Appointment Projection in the Design Space

Considering the classification for peripheral interaction (cf., Chapter 5.1), Figure 6.8 depicts, how the dimensions are covered by the Appointment Projection. The Appointment Projection is connected to a regular computer and its digital calendar (here: Google Calendar). By acquiring additional information about an upcoming appointment or silencing a reminder animation the user is interacting explicitly. Interaction is carried out by wiping gestures,

[4] The video figure illustrates the Appointment Projection: http://youtu.be/HmnwrXgWThU (Last Accessed: 02.10.2013)

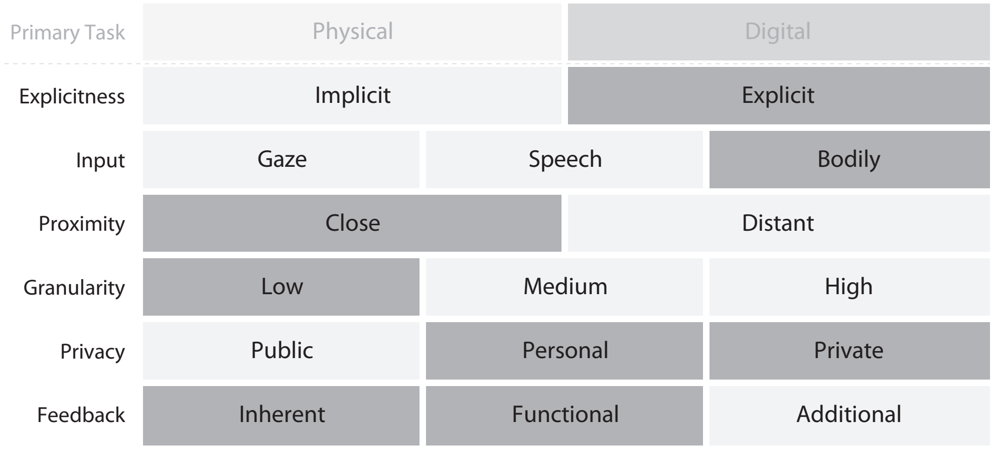

Figure 6.8: Appointment Projection located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by the Appointment Projection.

towards the user to acquire details and away from the user to silence the reminder. Hence, the interaction is at arm's length and therefore rather close by. Granularity is low as only two commands are supported. Calendar events are at least personal, in some cases they might be even private. Of course, wiping gestures include inherent haptic feedback through proprioception. Functional feedback is given through visual cues, for instance, information about the next upcoming appointment is shown as a balloon pop-up on the screen or the pulsating reminder animation is stopped.

In reference to the task-based perspective (cf., Chapter 5.2), staying up to date about upcoming appointments is an essential task for most office workers alongside their primary task. Checking what is up next is usually internally motivated. However, reminders are initiated by the system. Hence, our system supports both, retrieval of the next upcoming appointment but also silencing a reminder.

6.2.1 Background: Calendar Visualizations

Calendar data has been visualized by ambient means in several projects. The *Ambient Calendar* [194] uses an image with different elements to convey different information sources such as weather, public transport or calendar data. According to the state of the information sources, the image appearance changes. The Ambient Calendar uses clouds to represent calendar events. The more clouds are depicted in the sky the busier the day will be. *SpiraClock* [67] is designed as replacement for the standard computer clock. SpiraClock depicts the current time and approaching events (e.g., bus schedules but also personal appointments) arranged in a spiral. Through tool tips, by hovering over the clock with the mouse, more information about an event can be acquired. The *Ambient Dayplanner* [266] uses projected light to visualize the upcoming time and appointments. With the help of a tangible interface a reminder can be set. All projects are designed to give non-intrusive feedback [67] and fade into the environment [266]. This not only reduces interruption by notifications [58] and minimizes workload for the prospective memory [255], but also gives room to better manage one's time. For instance, constant awareness of the remaining time till the next appointment helps to decide, which tasks are still suitable to start or when to start preparing for the upcoming appointment [67].

The Appointment Projection pursues the same goals as the before mentioned systems but additionally offers more detailed information through peripheral interaction.

6.2.2 Designing and Building the Appointment Projection

The Appointment Projection[5] [102] comprises two aspects: (1) an ambient visualization projected onto the desk and (2) an interaction, which should be possible to be carried out in the periphery of the attention.

Designing the Visualization

Ambient systems should support users in keeping track of important information in a non-disruptive and aesthetically pleasing manner [194]. The important information of an appointment is: (1) the period of time until it starts (temporal distance) and (2) its duration. Hence, more detailed information (e.g., where to meet) should only be shown on demand in such a way that macro-attention shifts are minimized.

To identify an aesthetically appealing visualization, we first designed six calendar visualizations (see Figure 6.9). We based the design process on the four design dimensions of ambient systems by Pousman and Stasko [197] (cf., Chapter 4.3).

Information Capacity: All six designs have either a medium (i.e., temporal distance only) or high (i.e., temporal distance and duration) information capacity. Each sphere in the *Ball Path* depicts an appointment. The spheres fall into the boxes and – while the boxes move – at one point reach the bottom, indicating the start of the appointment. The *Sun* is based on a clock metaphor. The surrounding spheres – each depicting one appointment – are arranged based on their start time like on the clock. As closer an appointment is, the closer the sphere gets to the center. Additionally, the sphere gets darker. In the *Flower* visualization, each appointment is represented by a flower. The stem indicates the duration of the appointment while the remaining light grey depicts the time until the start of the event. The *Corner* shows every appointment as a stripe. The duration of an appointment is depicted by the thickness of a stripe, temporal distance is encoded by the distance to the black line. The *Spiral* depicts the current time in the center and all upcoming appointments lined up in a spiral. Light grey spheres depict free time while dark spheres depict appointments. The

[5] Chapter 6.2.2 is based on: Hausen, D., Boring, S., Polleti, J., and Butz, A. *Exploring design and combination of ambient information and peripheral interaction.* In Designing Interactive Systems (DIS), Work in Progress, ACM, 2012, 2 pages.

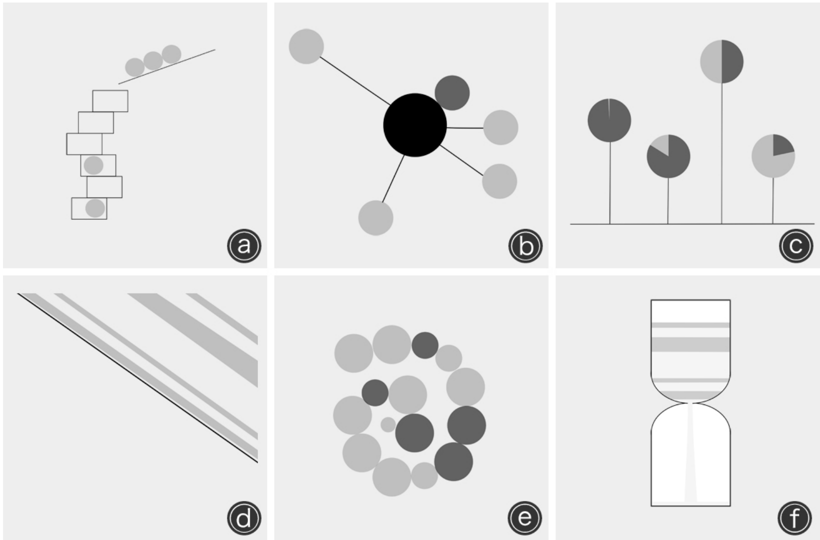

Figure 6.9: Design sketches for the Appointment Projection: (a) Ball Path, (b) Sun, (c) Flowers, (d) Corner, (e) Spiral, and (f) Hourglass.

size of a sphere depicts the duration. The *Hourglass* uses the thickness of layers to depict the duration of an appointment. Again, free time is depicted by light grey, and appointments by dark grey. Temporal distance is indicated by the distance to the hole. Once the "sand" starts to flow the appointment has started. All designs cannot display appointments, which are in parallel, especially with appointments lasting a whole day in parallel (e.g., birthdays).

Notification Level: All six designs include a steady animation, which helps to maintain awareness without unnecessary distraction [170]. Additionally we use a blinking animation as make-aware-notifications to indicate an approaching event.

Representational Fidelity: All visualizations are inspired by daily life, natures and metaphors for "time". Representational fidelity ranges from low to medium and uses symbolic as well as iconic (e.g., *Sun* and *Hourglass*) elements.

Aesthetic Emphasis: All sketches were drawn with a high focus on aesthetic emphasis.

Selecting the Visualization

To determine the visual appearance and understanding we conducted a paper-based user study with ten participants (three female). They ranged in age from 21 to 29 and eight of them used a digital calendar to schedule their appointments. To give them some sense for the use case we placed them in front of a regular computer and put one design after another (in randomized order) next to their keyboard – a location that could be used to later project the interface. We asked them to (1) interpret each design to find out if they are easily comprehensible without explanation apart from the fact that they represent calendar data. Afterwards we asked for (2) their favorite visualization in terms of design and functionality.

We rated all interpretations (in terms of time flow, meaning of spheres, meaning of sphere size, etc.) with 1 = other interpretation than meant by the designer, 2 = interpretation partly in terms of designer and 3 = interpretation in terms of designer. This lead to an overall ranking of: *Hourglass* ($m = 3.00$), *Corner* ($m = 2.77$), *Ball Path* ($m = 2.73$), *Spiral* ($m = 2.72$), *Sun* ($m = 2.40$) and *Flowers* ($m = 1.95$). Concerning best design and best functionality six participants named the *Spiral* in both categories, followed by the *Flowers* in terms of design and the *Corner* in terms of functionality. This led us to pic the *Spiral* as it has a reasonable good comprehension score and was very well liked by the participants.

Additionally we collected information about the preferred time span that should be depicted by the visualizations and which kind of appointments (past and upcoming) they want to see. Half of our participants opted for the current day to be displayed (while the other half opted for different amounts of hours, but all less than a whole day) and nine participants wanted to see only upcoming appointments.

Designing and Selecting the Interaction

We wanted to incorporate two commands into the Appointment Projection: (1) *details-on-demand* to acquire details about the next approaching appointment and (2) *snoozing* to silence the reminder animation.

During the evaluation we did not offer any suggestions or examples for interacting with the system or visualization but openly asked participants for each visualization (1) how they would like to interact and (2) which response they expect from the system.

Details-on-Demand: For the *Spiral*, the most prominent suggestion to acquire more details about the next appointment was to tap on the sphere depicting that appointment. However, we opted for the much less mentioned wiping gesture towards the user (cf., Figure 6.10 left), because tapping a distinct sphere most likely would not be performable in the periphery, as selecting the specific area would require at least visual attention. Considering the reaction of the system, most participants expected the details to appear on the projection on the desk. However, we opted for the second most mentioned idea, and offered it at the primary screen, as we assume that the current primary task and hence focus of the user will be on the primary screen most of the time. Hence, by displaying the information on the computer screen reduces macro-attention shifts.

Snoozing: Concerning snoozing we told the participants that we imagine a blinking animation to remind them about a close by appointment. Here, participants suggested to push back the sphere from the middle into the spiral. Again, this would require locating the specific sphere, which would require visual attention. Hence we opted for the counter interaction to details-on-demand and decided to use a wiping gesture away from the user for

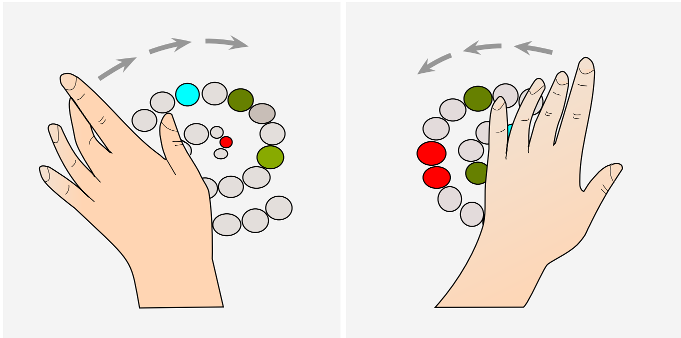

Figure 6.10: Interaction with the Appointment Projection (here located left of the keyboard): Wiping towards the user acquires details about the next upcoming appointment (as balloon pop-up on the display) (left) and wiping away snoozes a pulsating reminder animation (right).

snoozing (cf., Figure 6.10 right). As the goal of this interaction was to silence the animation, of course the reaction to this interaction is to stop the pulsating animation.

Implementation

The final design was implemented in C#. A projector (Samsung SP-P310ME Pocket Imager Projector) mounted to the user's desk projects the spiral onto the desk next to the keyboard. In the current implementation, the Appointment Projection is connected to the Google Calendar. Thus, for easier mapping, the appointments are represented in the same colors in the visualization as in the Google Calendar. Free time is depicted by grey spheres. In this first implementation we used camera tracking (Touchless SDK[6]), which required a one-time calibration process in the beginning. Whenever a wiping gesture for details-on-demand is recognized, the additional information about the next upcoming appointment is depicted as balloon pop-up on the primary display. If a wiping gesture for snoozing is detected, the pulsating reminder animation is stopped.

6.2.3 Initial Lab Exploration

To better approximate the usefulness of our ambient and peripheral calendar, we conducted an initial exploration in the lab. We were particularly interested in understanding the following: (1) the level of attention the peripheral calendar needs to attract to ensure that participants still efficiently work on their primary task while keeping track of their appointments, (2) to assess if the wiping gesture can be performed without high disruption and (3) how our system compares to existing, desktop-based solutions. We used a dual task setup (cf., [90]) simulating a scenario that closely matches everyday office practice: a primary task (we identified typing as the most prominent example of everyday office tasks) and the secondary task of keeping track of upcoming events.

[6] http://touchless.codeplex.com (Last Accessed: 25.06.2013)

Interfaces

To figure out the best attention-to-productivity ratio, we had three conditions, each of which varied in terms of salience: In the *Peripheral No Reminder (P1)* condition, users had to explicitly acquire additional information using a wiping gesture (no attention drawn). In *Peripheral Appointment (P2)*, the upcoming appointment (i.e., the sphere) started pulsating two minutes before the event begins (some attention drawn). In the *Peripheral Spiral (P3)* condition, the whole Spiral started pulsating two minutes before the upcoming appointment (much attention drawn). In each of the conditions, a balloon pop-up is shown after the users perform a wiping gesture towards themselves. They can silence the pulsating reminder by a wiping gesture away from themselves.

To investigate the comparability with existing calendars, we mimicked three desktop calendar applications increasing in disruptiveness (i.e., ranging from no attention to much attention drawn): In the *Calendar No Reminder (C1)* condition, only a system tray icon was shown and a double-click on it opened a textual calendar overview. In *Calendar Taskbar (C2)*, a minimized pop-up window blinked in the taskbar as reminder. Finally, *Calendar Pop-Up (C3)* used a pop-up reminder capturing the input focus. *C2* and *C3* also included the icon in the system tray to access an overview about the appointments.

Participants

We recruited twelve participants (four female), ranging in age from 22 to 33 (average age was 27). They rated their typing skills above average (*median* = 5) on a 7-point Likert scale (1 = extremely bad, 7 = extremely good). Half of them regularly use digital calendars.

Procedure

After briefly introducing the overall task, users were asked to type a text (a fairy tale by the Brothers Grimm) for three minutes without any disruptions to determine their typing skills as the baseline. Subsequently, participants received another printed fairy tale that they had to type as their primary task. All texts were long enough so that nobody managed to finish the text during one run. Once an appointment was approaching, our participants had two minutes to react: they had to get up from the chair (to simulate leaving for an appointment), which we measured through a pressure sensor mounted to the chair. We assume, the act of getting up nearly presents as much disruption as if they really had to leave the work space. We instructed them to leave the chair whenever convenient during these two minutes. By narrowing down the time slot to two minutes, we established a strict time frame for users to react but also offered them the freedom to type for instance until the end of a sentence. We believe that the freedom of choice while still gaining enough attention is a key attribute of a good reminder system. Additionally they had to state the name with whom they are having a meeting, to ensure that they were aware of the appointment's details. Meanwhile, we asked users to (1) type as fast and correct as possible while (2) not missing any appointments.

For each interface, we measured the following variables for both intra-system (i.e., only comparing the peripheral interfaces) and inter-system comparison (i.e., always comparing C_i to P_i): (1) *Reaction Time* (time between the start of the two minutes of the reminder till participants got up), (2) *Error Ratio* (ratio of typing errors with a reminder system and typing errors without one), (3) *Loss of Productivity* (keys per second typed in the two minutes time frame, which they could use to get up compared to two minutes typing in the baseline) and (4) *Interactions* to acquire details about an appointment (wiping gestures, or opening the calendar overview in the calendar conditions). Typing errors are based on Levenshtein distance [152]. We counterbalanced the order of the six interfaces among our participants to minimize order effects. Furthermore, for each condition, each user had a different text as well as a different calendar set (with three events each) to rule out learning effects. We assigned each calendar set and text randomly to each interface for each participant prior to the experiment.

Preliminary Results

We gathered both, quantitative (e.g., error ratio, loss of productivity) and subjective data, for the evaluation of the Appointment Projection.

Reaction Time: When looking at the reaction time (time between start of the two minutes time frame and leaving the desk) in Figure 6.11a, one can clearly see that as the reminder captures more attention, reaction time decreases. This is even more the case for the calendar based systems in comparison to the peripheral systems. As we intentionally left room for our participants to leave at their liking in a two minutes time frame, leaving very early is not necessarily a good sign, as working time might get lost (cf., next paragraph on "Loss of Productivity"). However, participants reacted rather early, with the longest average reaction time for *P1* (m = 44.2s, sd = 26.3s) and *C1* (m = 43.4s, sd = 23.3s), which is still way below the maximum of 120 seconds. This might be due to the lab study setting, which drew much attention to the peripheral task – keeping track of the appointments – and additionally participants did not have any incentive to finish as much text as possible before leaving. For both, the medium salient systems *P2* (m = 37.9s, sd = 18.4s) and *C2* (m = 22.4s, sd = 25.2s) and the most salient systems *P3* (m = 32.9s, sd = 17.6s) and *C3* (m = 16.0s, sd = 17.7s), one can observe that the calendar systems lead to much shorter reaction times than the peripheral systems.

Loss of Productivity: In line with the findings on reaction time, Figure 6.11b reveals that the productivity (keys per second typed in the two minutes time frame, which they could use to get up, compared to two minutes typing in baseline) decreases as salience increases for both the peripheral and desktop interfaces. That is, although the error ratio (during the entire trial) was high for *P1* (cf., next paragraph on "Error Ratio"), the productivity suffered the least (m = 0.59%, sd = 0.21%). Although slightly higher, *P2* (m = 0.68%, sd = 0.20%) has a comparable decrease in productivity. However, *P3* (m = 0.85%, sd = 0.13%) results in a high loss of productivity, which most likely means that participants had the feeling of being

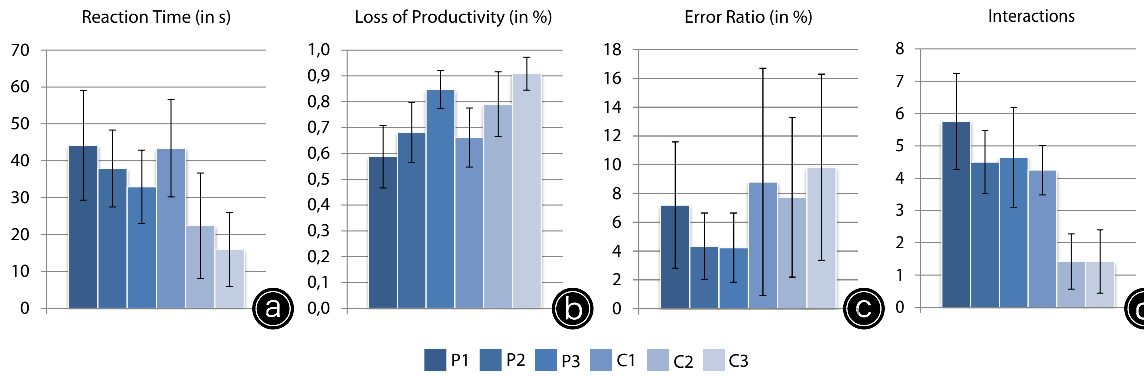

Figure 6.11: Quantitative results of the lab exploration. Error bars are 95% confidence intervals.

forced to leave. While the same trend is shown for desktop interfaces, each of them had a slightly higher loss than the comparable peripheral interface. We assume that the reminders showing up in the user's focus (i.e., on the display) cause this effect. When comparing peripheral interfaces and desktop applications it is obvious that loss of productivity was even more severe for the calendar based interfaces: *C1* ($m = 0.66\%$, $sd = 0.20\%$), *C2* ($m = 0.79\%$, $sd = 0.22\%$) and *C3* ($m = 0.91\%$, $sd = 0.11\%$).

Error Ratio: When only looking at the peripheral interfaces, the data suggests that *P1* ($m = 7.20\%$, $sd = 7.75\%$) had a dramatically higher error ratio compared to both *P2* ($m = 4.34\%$, $sd = 4.07\%$) and *P3* ($m = 4.24\%$, $sd = 4.24\%$), which both performed equally. This may be explained by the user's insecurity of missing an upcoming appointment, as there were no reminders. When comparing each peripheral calendar to its desktop counterpart, Figure 6.11c suggests that the peripheral interfaces with medium (*P2*) and high (*P3*) attention capturing mechanisms have about half the error ratio of the desktop versions (*C2*: $m = 7.74\%$, $sd = 9.79\%$, and *C3*: $m = 9.83\%$, $sd = 11.42\%$). This noticeable difference most likely resulted from users being distracted when something appears on the display they are performing the primary task on. Our peripheral interfaces, on the other hand, only drew attention in the periphery, presumably presenting less distraction to the main task. The two interfaces with no reminder (i.e., *P1* and *C1*) have comparable error ratios (*C1*: $m = 8.80\%$, $sd = 13.95\%$). As before, we assume that this is caused by the participants regularly checking the calendar to not miss an appointment. Errors in the secondary task (i.e., missed appointments) appeared in all conditions rarely. Hence we did not further analyze them.

Interactions: When looking at the average number of interactions in the secondary task (i.e., wiping gestures in the peripheral condition, or opening the overview through double-clicking on the calendar icon in the three calendar conditions) in Figure 6.11d, one realizes that peripheral conditions cause much more interactions to explicitly acquire details. Participants even interacted more than appointments were present during the study (three appointments) (*P1*: $m = 5.8$, $sd = 2.6$; *P2*: $m = 4.5$, $sd = 1.7$; *P3*: $m = 4.6$, $sd = 2.7$). The same is

true for no reminders at all in the calendar condition (*C1*: *m* = 4.3, *sd* = 1.4). However, even with reminders on the primary display, participants still sometimes checked the overview of appointments (*C2*: *m* = 1.4, *sd* = 1.5; *C3*: *m* = 1.4, *sd* = 1.7). With the smaller error ratio and slightly less loss of productivity for peripheral tasks, we assume that the interaction (i.e., wiping gestures) in fact could – even in a short lab study – be performed in the periphery, or at least the interaction with the ambient visualization is less distractive than the notifications, which provide detailed information thus are not asking the user to explicitly acquire it.
Snoozing a reminder was only available for *P2* and *P3*. Overall it was rarely used but slightly more often for *P3* (*P2*: *m* = 1.3 *sd* = 1.2; *m* = 2.1, *sd* = 1.5). This indicates that overall the reminder was not too distracting, thus not requiring silencing it every time.

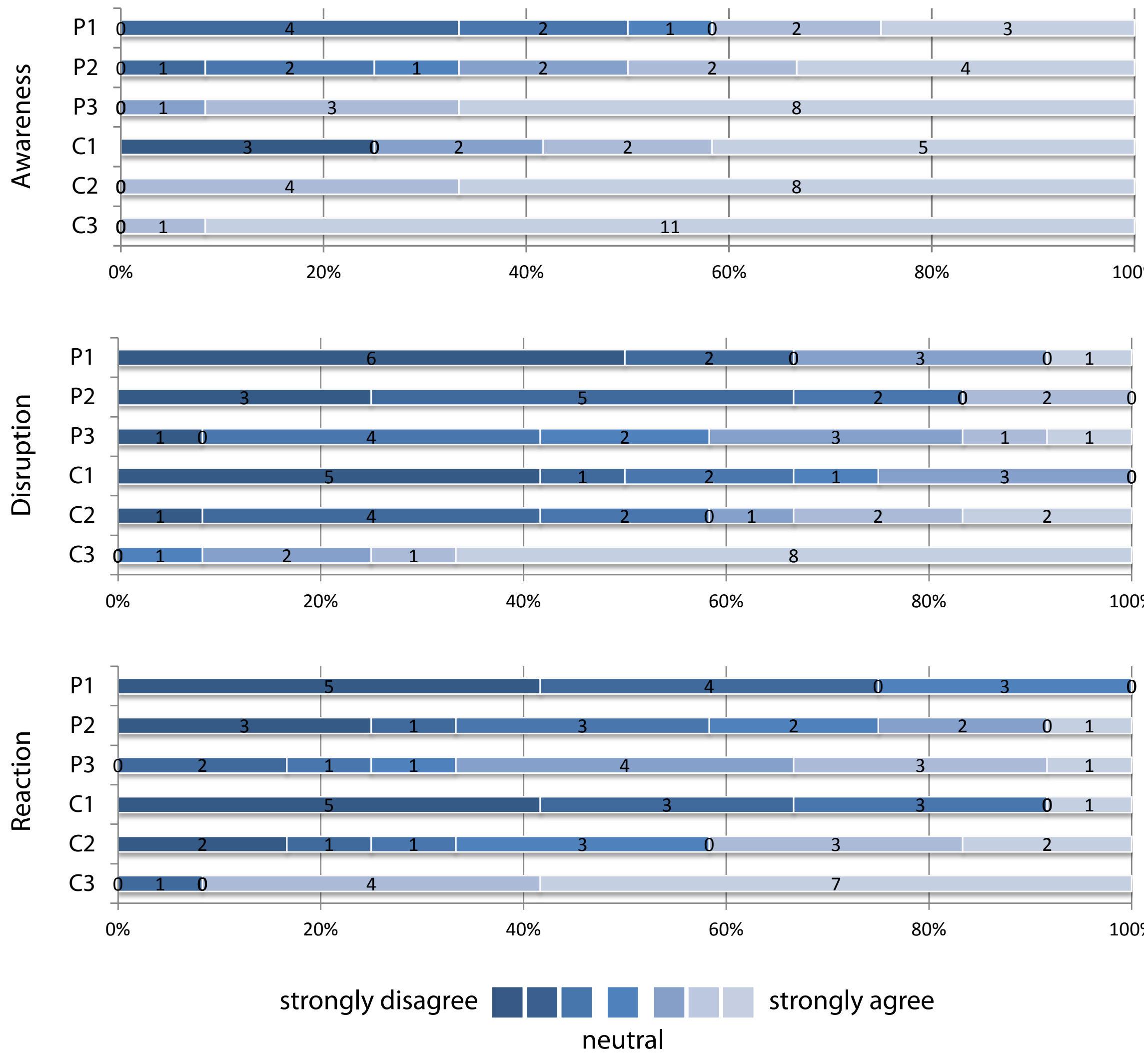

Figure 6.12: Subjective results (7-point Likert scales) for (Q1) awareness of the reminder (top), (Q2) disruption while writing (middle) (Q3) forced to react immediately (bottom)

Subjective Ratings: Subjective results are summarized in Figure 6.12. The questions were rated on a 7-point Likert scale (1 = I totally disagree, 7 = I totally agree). For all questions *(Q1) awareness of the reminder*, *(Q2) disruption while writing*, and *(Q3) forced to react immediately* the answers show ratings increasing from *P1* to *P3* (and *C1* and *C3* respectively). Furthermore, comparing the corresponding peripheral and calendar interface, the peripheral one is rated more positive, thus the peripheral interfaces (1) presented more awareness than their desktop counterparts, (2) caused less disruption, and (3) were not rated as forceful as the desktop applications. When only analyzing the peripheral interfaces, Figure 6.12 reveals that *P3* presented the most awareness, but – at the same time – was considered the most disrupting and forceful interface. Overall, users feel more disrupted (and forced to react) when awareness increases.

Summarizing the Results

We conducted the initial lab study to evaluate (1) the level of attention that is attracted by the projection, (2) the suitability of the wiping gesture and to (3) generally compare our design to standard calendar reminders. All in all, our proposed peripheral interfaces show a trend of performing better compared to desktop solutions that present a similar level of salience. We attribute this to the location in the periphery, which reduces disruption in the primary focus and still offers enough awareness if needed.

Having a closer look at the different levels of peripheral interfaces, *P1* (without reminder) and *P3* (with the entire spiral pulsating as reminder) offer a different set of advantages. While *P1* does not disrupt users, it requires them to constantly check the calendar data and appointments. In contrast, with *P3*, users are well aware of the reminder but feel forced to react immediately. Consequently, based on this data we consider *P2* as the best trade-off: its error ratio is comparably low as the one for *P3*. At the same time, it has less loss of productivity. Furthermore, *P2* is perceived as non-disruptive as *P1*, but offers higher awareness (and thus slightly more pressure to react to the reminder) compared to *P1*.

Concerning interaction, all peripheral conditions lead to more interactions than the respective calendar condition. However, as we saw from the other quantitative results, peripheral conditions still generally performed better. Pushing an interaction to the periphery in a lab exploration is very hard to achieve, as the participants are very focused on the tasks at hand, even the ones designed to be peripheral. However, we consider that as a first indicator that the interaction could be carried out with only low effort and hence was not very disrupting. This leads us to believe that not only tangible or graspable interaction is suitable for peripheral interaction but also freehand gestures can be successfully applied.

Overall, these results only present a first approximation of interacting with important information in our periphery. Testing such systems in the lab results in problems: (1) an ambient system needs to blend into the periphery to show its full capability. This is hard to achieve in an artificial setting (such as a lab) where the user focuses on a new system. And (2) peripheral interaction needs training to be truly peripheral and be carried out without focusing one's attention on it. To manifest our findings we conducted an in-situ deployment subsequently.

6.2.4 In-Situ Deployment

To validate the findings of the lab study and to collect insights on peripheral wiping gestures in a real life setting we conducted an exploratory two-week long in-situ deployment with three participants[7] [225].

Changes to the Implementation

Before distributing the system to our participants we carried out some minor changes concerning hardware and software. These changes are based on insights from the lab study as well as several informal talks[8] about the design and comprehensibility of the visualization.

Hardware: The first implementation was based on camera tracking. As we saw in the lab study, this was sometimes unreliable, especially in changing lighting conditions, which most likely would be the case if deployed at a regular desk for weeks and used throughout the day. In the revised implementation we relied on two infrared distance sensors (Sharp GP2D12), which are connected to and controlled by an Arduino Duemilanove. The two distance sensors are fixed next to each other on a thin surface. When wiping above them, the software evaluates, which sensor was covered first and thereby determines the wiping direction. Switching from camera based tracking to sensor based tracking decreased the range on the desk in which the interaction is tracked. On the one hand, this requires a bit more precision when interacting, as the user has to be in the correct area, however, deployed on a regular desk this also minimizes false positives during regular movements while working (e.g., grasping a pen).

Software: We slightly changed the visualization. In the previous implementation we offered three different sphere sizes depicting three different time frames (15 minutes, 30 minutes and one hour). However, appointments, which lasted longer than one hour, were depicted by several spheres. Hence, there are no means of telling whether these two spheres represent two consecutive appointments or one longer appointment. To distinguish this, we now visualize longer appointments by chained spheres. Additionally the sphere in the middle can get even smaller indicating that it is less than a quarter of an hour until the next appointment.

In a one-time set up procedure, participants also have to select the serial port they plugged in the Arduino, which controls the gesture tracking. Additionally we introduced a control window where participants put in their Google credentials to access their calendar data. Moreover, they could choose, which calendars to display on the desk (in case they organized their appointments in different calendars), how long before the appointment they wanted to be reminded by the pulsating animation and last but not least, they had to state whether they

[7] The in-situ deployment was carried out by Franziska Straßer under the supervision of Doris Hausen: Straßer F. *Evaluation of the Ambient Appointment Desk*, Bachelor Thesis, University of Munich (LMU), Germany, 2011

[8] One of them being with Don Norman.

positioned the projection and the gesture tracking on the left or right side of their keyboard. Wiping gestures towards (acquiring details) or away (stopping a reminder) from the user was interpreted according to this setting. We automatically fetched the calendar data every 30 seconds, in case new appointments were entered into the calendar or old ones were deleted. However, we also offered a manual button in the control window to refresh the data in case a participant wants to see the changes right away.
One final change was only carried out after a pilot study. Originally participants were free to choose, which reminder animation they would like to use – just the appointment, thus its respective sphere, pulsates or the whole spiral pulsates. Because the participant in the pilot study – immersed in his daily tasks – never recognized the pulsating appointment we opted for only offering the whole pulsating spiral as reminder. With the only limited number of participants this removed one variable and hence provides us with more data about this one specific reminder.

Participants

We carried out the in-situ deployment with three participants (one female) ranging in age from 27 to 30 (average age 28). All three were working in an office and organized their appointments with the help of Google Calendar.

Procedure

Each participant had the Appointment Projection installed for two weeks at their regular desk. During these two weeks we conducted three semi-structured interviews and logged all interactions with the spiral.

Week 1: During the first meeting we conducted a semi-structured interview asking about the general usage of digital calendars to uncover typical usage patterns of each participant. Afterwards we mounted the projector to the desk. The users could decide whether they want the projection on the left or the right side of their keyboard. We just made sure that the projection is visible and reachable for interaction. Afterwards we installed the software, did the initial setup together with them and asked participants to keep it running whenever their computer is turned on. We introduced them to the system and showed them how to interact with it. Additionally we explained to them which information we were logging: (1) *time* and *date* of each appointment, (2) *name* and corresponding *calendar* of each appointment as MD5 hash, to preserve privacy but being able to clearly distinguish all appointments, (3) *when* and *how long* the reminder was pulsating and finally (4) *how* (details-on-demand or snoozing) and *when* the user interacted via wiping gestures. With this data we could recreate the visual appearance of the spiral at any point in time during the deployment.

Week 2: At the beginning of the second week we met again and asked about their experience with the Appointment Projection. We wanted to find out if any problems occurred and how they perceived the reminder and the interaction with the system. Afterwards we left them alone again for another week. After the second week we returned and repeated the interview to uncover any usage changes between the first and second week. Before leaving we took down the system and uninstalled the software.

Results

As we could not find any change in the logged data as well as in the statements of the participants, we did not differentiate between the first and the second week with the Appointment Projection but state the results as a whole.

Usage of Google Calendar: Our participants usually checked their calendar every morning and often also in the evening before going home to get an overview about the current or the next upcoming day. Two participants afterwards closed their calendar while one participant had it visible most of the time on a secondary display. Roughly a third of all appointments are repetitive appointments, which our participants usually have in mind and did not need to be reminded about. Concerning reminders, only one participant used pop-up reminders rarely for very important appointments. All stated that they are generally bothered by them as they disrupt them. The participants agreed that time and duration are the most important information about an appointment and enter additional information (such as the location) very rarely and only for special events.

Usage with the Appointment Projection: On average the Appointment Projection was running for 5 hours and 38 minutes per day per user and visualized 126 calendar events during the whole study. These events lasted between 20 minutes and 5 hours (however, the typical time span was one hour). The reminder time was 10 minutes by default but was changed to 5 minutes by one participant as she indicated that this is the time she usually has to leave. Hence, she did not use the Appointment Projection to remind her that there generally is an appointment, but that she is supposed to leave now. The 24 hour display was considered enough by the participants. Two people even started to add events to their calendar (either personal appointments that they usually did not keep in their work calendar, or events which were intended to structure the day but were not actual appointments), because they enjoyed seeing them on the desk. The Appointment Projection was preferred for a rough overview over the Google calendar and considered useful in their daily routine. Participants liked the color mapping, as it was based on the colors they already used in their calendar and hence was easy to remember. However, two participants stated that they had problems distinguishing the different sizes of the spheres and think that they do not need that level of detail and less sphere sizes would work better for them.

Interaction: Participants over the course of the study performed 70 wiping gestures towards them to get details-on-demand, with only nine of them being performed while the spiral was pulsating. By performing the gesture, details for 55% of all appointments were shown. However, for each appointment that they called up additional information they did that on average twice. For snoozing a reminder, 28 wiping gestures away from them were performed, thus silencing 44% of all pulsating reminders (however, we cannot tell, if participants have been at the desk every time a pulsating reminder appeared). Using gestures was considered to be fun according to one participant, and all participants agreed that they automatically knew which wiping gesture to perform for which interaction right from the beginning. However, they all looked at the spiral while interacting, thus they focused their visual attention on it. Nevertheless one participant reasoned that this was only an automatic reaction, as one is so used to looking at the interaction. Additionally, we encountered the issue that very often both gestures were performed in direct succession. This mostly was not intended by the participant, but happened while positioning the hand for the interaction. Thus, the preparation phase (cf., Chapter 3.3) is already (falsely) interpreted as the stroke.

Summarizing the Results

The Appointment Projection was well received. As participants started to add additional events to their calendar – which they usually did not put in their work calendar (e.g., for structuring time) – we believe that the visualization was useful and enjoyable for them.

Participants did make use of acquiring details about their upcoming appointments. Surprisingly it was not the reminder that usually triggered that interaction. But participants did not rely on reminders before and therefore might be used to check their next appointments every now and then. Participants attested us that we found a good mapping for the two commands by the wiping gestures, however these opposing movements also caused false positives.

With only three participants, results of course can only be seen as a first indicator. However, as this is the first approach to use freehand gestures for peripheral interaction, we believe that even these limited findings offer the insight that it is worth investigating freehand interaction for peripheral interaction in more detail.

6.2.5 Lessons Learned

The Appointment Projection is the first project in the field of peripheral interaction which makes use of freehand interaction. Two explorative studies – one in the lab and one in the field – were carried out to gather first insights on the general feasibility of freehand gestures for peripheral interaction.

Summary and Limitations

The Appointment Project is designed to offer ambient awareness about upcoming appointments, while offering the same amount of information as traditional calendars – at least on demand. However, acquiring more information is carried out by freehand wiping gestures in contrast to switching to the calendar and thereby switching windows and focus.

In the lab study, we compared three projected interfaces and three calendar based interfaces differing in salience. We found that the projection tended to perform better concerning reaction time, productivity loss and errors than the respective calendar interface although the number of interactions (to acquire details about the next appointment) increased. We consider this as a first indicator that the interaction was easy to perform without considerable disruption. However, in the field study we found that participants tended to look at the visualization while performing the interaction. This might be partly based on habit but could also be the case because the interaction has not shifted to the periphery in two weeks with the system. Nevertheless, the system was used regularly and independent of the reminder animation. In other words, they used the system to acquire details whenever they were interested in them, thus they were motivated intrinsically to use the system. This can be seen as first step to a successful integration of the wiping gestures into their daily routines. Overall, the Appointment Projection offered a good overview but the reminder animation was sometimes considered to be distracting.

As already hinted at, theses findings are only a first glimpse into the suitability of freehand gestures for peripheral interaction. The lab study could provide a comparison to other interfaces, however participants most likely were very focused on the given task, thus the interaction hardly shifted to the periphery. Chances of shifting to the periphery increase when deploying the system in-situ. However, with only three participants insights are also limited. We still consider this exploration a success in terms of introducing freehand gestures to peripheral interaction. More in-depth evaluations, also comparing freehand gestures to graspable and touch interaction, will be presented in Chapter 7 and Chapter 8.

Generalizable Findings for Peripheral Interaction

The Appointment Projection was designed for keeping track of appointments. However, from our two explorations we can derive some findings, which go beyond this use case.

Increase of Information Capacity: Several systems already tried to offer an overview on calendar data in an ambient way. However, these visualizations – being ambient of course – lack detailed information. This is working well, if the goal is to just provide an overview. Nevertheless sometimes more details are needed. By using peripheral interaction, this information can be provided without completely shifting away from the main task. The additional information and the corresponding interaction can still – in the spirit of ambient information – reside in the periphery. Consequently we are able to remove the forceful disruptions without losing any information. This of course cannot only be applied for calendar data but for many other use cases that are already found in the literature for ambient information such as bus schedules or monitoring emails.

Habituation: As we already established for StaTube (cf., Chapter 6.1.6), habituation is an important part of an interaction shifting to the periphery. However, habits also have to be broken. While the wiping gesture itself was very clear to our participants, they still all stated to look at their hand and thus at the visualization while performing it. Kahneman [141] calls this *looking accompanied by internal processing*, thus looking at something although there is now visual clue or reason to look at it (cf., Chapter 2.1.1). However, once people are very used to a task, they can easily perform it without looking, especially if there are other visual cues that might capture their attention (e.g., the current primary task).

More Interaction vs. More Distraction: Ironically, we provided less distraction by actually adding interaction to the overall work flow. With traditional reminders all information is already present that now has to be explicitly requested by the user. However, these interactions can be carried out whenever the user feels comfortable doing it, thus negative effects of interruptions, for instance the interruption and resumption lag, might be decreased. Consequently, the number of single interactions is not a fitting measurement to assess the success of peripheral interaction.

Freehand Gestures: Finally, most obviously we applied freehand gestures to peripheral interaction. As productivity loss and errors decreased although we increased interaction, we consider the use of freehand gestures a success. Nearly all problems that occurred during both studies can be attributed to technical difficulties. Tracking freehand gestures is still a challenge, although with new technology such as Leap Motion[9] – which was not yet available when we conducted the study – these issues will most likely be less severe. Nevertheless, our wiping gestures often interfered with only positioning the hand above (or below in case of the camera tracking in the first study) the tracking device. Although the mapping between gesture and command was very clear to the users, this issue needs to be taken into account in future projects.

[9] https://www.leapmotion.com (Last Accessed: 28.06.2013)

Chapter 7

Comparison of Interaction Styles

Synopsis

The following chapter offers two comparative studies: The Peripheral Music Controller and Interaction Styles & Feedback.

The Peripheral Music Controller supports controlling an audio player application through graspable, touch and freehand interaction. In an eight week in-situ deployment we found that participants used the peripheral devices extensively (i.e., significantly more than the mouse and the traditional GUI) and often without the audio player in focus on the computer's display. They also considered interaction to only cause little mental load. Although all devices were generally fit for peripheral interaction, participants liked the graspable device best.

Interaction Style & Feedback is a lab based exploration again comparing graspable, touch and freehand interaction. While the Music Controller solely relies on inherent haptic feedback and functional auditory feedback, this project includes different additional visual feedback types. In this study, graspable interaction caused a higher loss of performance and longer duration of interruption and resumption lag in comparison to touch and freehand interaction. In contrast, feedback did not have any significant effect, even compared to no feedback at all. However, participants strongly argued for having feedback.

The previous chapter introduced two first explorations for peripheral interaction, one – StaTube – exploring graspable interaction and one – the Appointment Projection – investigating freehand gestures. They showed promising results for both interaction styles and their suitability for peripheral interaction.

This chapter now describes two comparative studies, which explore graspable, touch and freehand interaction and contrast them to each other. The Peripheral Music Controller (Chapter 7.1) supports audio control and was deployed in an eight week in-situ study. Interaction Styles & Feedback (Chapter 7.2) supports email management and was evaluated in the lab.

7.1 Exploration: Peripheral Music Controller

The Peripheral Music Controller[1] [105] is designed to compare three interaction styles – graspable, touch and freehand interaction (see Figure 7.1). Many people listen to music while carrying out manifold other tasks on the computer. While most of the time music is just playing in the background, every now and then users interact with the music player to start or stop music, skip a song or change the volume. These three tasks are all rather simple side tasks and are already supported by dedicated media keys on many keyboards. However, pressing a dedicated key on the keyboard is a rather precise movement.

We built a prototypical implementation for all three interaction styles based on an initial paper-based exploration and evaluated them in an eight week in-situ deployment together with the already state-of-the-art media keys.

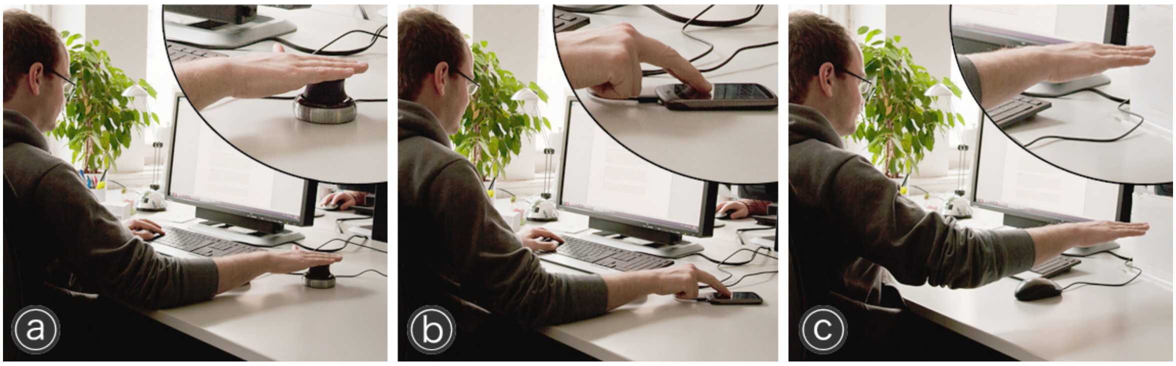

Figure 7.1: User with all three interaction styles – (a) graspable, (b) touch and (c) freehand – to control his audio player.

[1] Chapter 7.1 is based on: Hausen, D., Richter, H., Hemme, A., and Butz, A. *Comparing input modalities for peripheral interaction: A case study on peripheral music control.* In Human-Computer Interaction (INTERACT), Springer, 2013, 162-179.

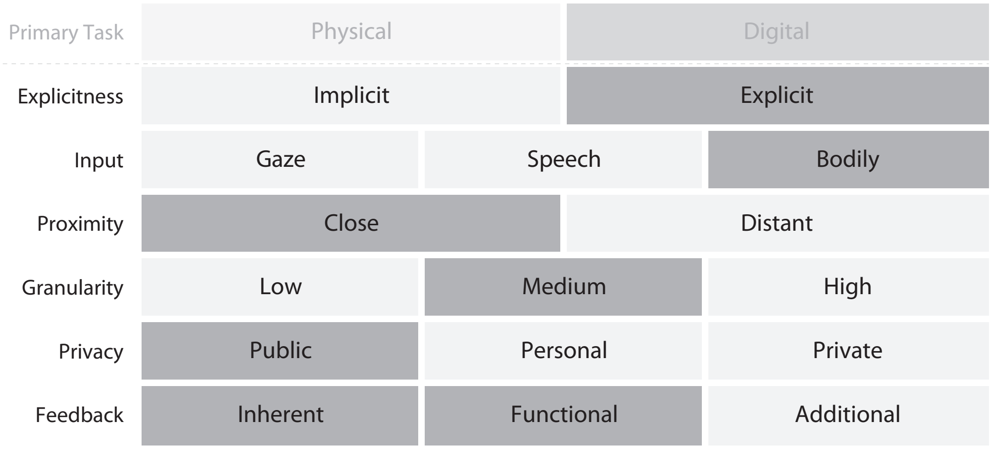

Figure 7.2: Peripheral Music Controller located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by the Peripheral Music Controller.

Peripheral Music Controller in the Design Space

Concerning the classification spanned in Chapter 5.1, the Peripheral Music Controller is designed to be used alongside digital primary tasks (see Figure 7.2). The user interacts with the prototype to explicitly change the music with his hands either through a graspable interface, touch input or freehand gestures. Additionally, we explore media keys as fourth input style. For all four conditions proximity is close by. Granularity is medium with six supported commands. The music somebody is listening to can be considered as public (not based on any user data). Inherent feedback through proprioception as well as functional auditory feedback due to the task itself – listening to music – is given. Users can for instance hear whether a song starts or stops or is skipped.

Considering the task-based perspective, the Music Controller is user-driven, thus the users decide when to interact. The task, controlling the music player, is usually additional to another primary task (such as writing an email, browsing the web, etc.) and manipulates the state of the music player (e.g., changes the volume) or retrieves content (e.g., a new song).

7.1.1 Background: User Interfaces for Audio Control

To find the best possible mappings for all peripheral interaction styles, we explored related interfaces for controlling music.

Graspable Interfaces

Most graspable interfaces for music control are either cube- or knob-based. The *Music-Cube* [6] is a cube-shaped object, which includes a big round button on one side similar to Apple's iPod click wheel. Starting music, setting it to shuffle and volume control is included.

Even playlists can be accessed through the device. With the *GestureCube* [145] users can control music (e.g., pause/play, next/previous, shuffle, volume) by turning, shaking and spinning the device. *Physical Shortcuts* [74] are also implemented as cube because this was the best shape in a comparison to cylindrical and hybrid shapes. *KeyKnob* [73] relies on the location that a knob is placed on (e.g., a cabinet) to control a media player. Andersen [10] compares buttons to a rotary controller and found that users preferred the rotary controller although no significant difference in terms of errors and performance could be detected. Others imagined more abstract forms, among them pyramids that can be unfolded or shapes inspired by nature such as flowers with moveable leaves [40].

Touch Interfaces

Prihonen et al. [195] investigated touch gestures on mobile devices to control a media player. A similar project is the commercially available *Buddy Remote*[2], which enables users to control media applications on the computer via touch gestures on their mobile device. In the automotive context, Döring et al. [68] investigated touch gestures on a steering wheel to reduce visual shifts while driving to interact with the car's audio player. They found that participants, when being free to choose whether to interact with the traditional radio or with gestures, more often opted for the gestures. Gestures they supported relied on swiping or taps but also drawing shapes, such as the arrow usually symbolizing play.

Freehand Interfaces

BodySpace [224] uses simple gestures, such as tilting a device backwards or forwards to encode binary commands (e.g., increase or decrease volume). To increase the information capacity they rely on different locations in reference to the body to carry out the commands, for instance tracks are skipped by tilting the device next to the head or volume is changed by tilting the device next to the pocket. Mäntyjärvi et al. [177] make use of the accelerometer to track different gestures to control a DVD player while Premaratne et al. [199] focus on different gestures, which are easy to capture via camera based tracking. Hand postures differing in the number of spread fingers (e.g., fist for "start" and thumbs up for "up") were considered easy to track and also mapped well to commands used to control a media player.

While all of these projects aim at controlling audio, or at least media content, some already also consider the reduction of visual or cognitive attention (e.g., [68, 145, 195]). Inspired by all these different input styles we set out to design our three peripheral interaction styles.

7.1.2 Designing and Building the Music Controller

To design the interaction styles we tried to find mappings, which are easy to learn and remember and do not require unnatural hand or finger postures. One approach to achieve this

[2] http://www.iospirit.com/products/remotebuddy/ (Last Accessed: 02.07.2013)

ask users, which gestures they consider to be the best fit [244]. We applied a two-step process. We extracted potential gestures for each of the interaction styles from related work and afterwards asked users to carry them out with the help of paper prototypes and rate them.

Interaction Possibilities

We selected the three most common interactions with an audio player for our prototype: pause/play, next/previous and volume control. All three are also supported by media keys, which similar to stereo equipment often rely on well established symbols (e.g., ▶ ⏮ ⏭) to indicate, which command is linked to which button. However, when aiming for peripheral interaction through graspable, touch and freehand interaction, there often is no suitable location for such hints. Additionally, peripheral interaction wants to reduce visual attention, hence we do not want to rely on visual indicators. Thus interaction has to be easy to remember. To find the best possible mapping we derived potential gestures for all three interaction styles from related work (cf., Chapter 7.1.1) or based them on direct metaphors such as turning a volume knob. Table 7.1 shows all collected gestures for each interaction style.

Table 7.1: Possible input mappings, and the finally selected one (bold and in Figure 7.4). Some gestures (e.g., one/two finger gestures) were presented individually but are summarized here.

	Graspable	Touch	Freehand
Pause/Play	• **click** • double click • long click	• **one/two finger tap** • one/two finger double tap • one/two finger long tap • draw square/arrow	• **hold vertical hand in midair**/thumbs up • move horizontal hand up/down • draw square/arrow
Next/Previous	• **tilt knob left/right** • turn knob left/right • push down & turn knob left/right	• **one/two finger swipe left/right** • tap left/right area on the surface	• **flick left/right** • thumb left/right
Volume	• **turn knob left/right** • push down & turn knob left/right • til knob up/down	• **one/two finger swipe up/down** • circle left/right (cf., iPod click wheel) • two finger circle left/right (cf., rotation on touch displays) • tap top/bottom area repetitive/long	• **move horizontal hand up/down** • grasp gesture up/down or left/right (cf., slider) • circle with hand/finger left/right • thumbs up/down • pinch gesture

Study with Paper-Based Prototypes

After collecting different gestures for each device we carried out a paper-based study to find the best possible mapping for each peripheral device.

Paper Prototypes: Our paper prototypes were built out of white cardboard [256] to mimic the different devices and resemble existing artifacts such as touch pads (see Figure 7.3). We used a box (Height $\times$ Width $\times$ Depth: $6 \times 8 \times 5$ cm) to imitate a 3D gesture tracking device. As touch sensitive surface we built a tilted paper surface (Height $\times$ Width $\times$ Depth: 0-2 $\times$ 13 $\times$ 13 cm). For the graspable device we opted for a knob (in contrast to a cube) as (similar to the StaTube, cf., Chapter 6.1) we consider a knob to be operable from any direction, without previous knowledge about the orientation. We used a brass fastener to mount the knob (Height $\times$ Diameter: 5.5×4 cm) on a bottom panel (Height $\times$ Width: 20×20 cm for stability), thus it could be turned, tilted and pressed down.

Participants: Overall 18 participants (six female) took part in our study. They ranged in age from 21 to 31 years with an average age of 25 years.

Procedure: Every participant carried out all potential gestures with all devices (repeated measures design). Consequently our independent variables were *interaction style* (graspable, touch, freehand), *command* (pause/play, next/previous, volume) and the previously listed 35 *gestures*. We counterbalanced interaction styles and presented the gestures in a randomized order within one interaction style. Participants could use whichever hand they preferred but we located the device in their periphery, thus not directly in front of them. Additionally we asked them to try to minimize gazing at the device and imagining being engaged in another task. Each gesture was first presented by the instructor and afterwards carried out by the participants themselves. We asked them to rate each gesture as either "bad", "okay" or "good". Furthermore we asked for the preferred gestures for each interaction style and command. Afterwards participants were asked to fill out a short questionnaire.

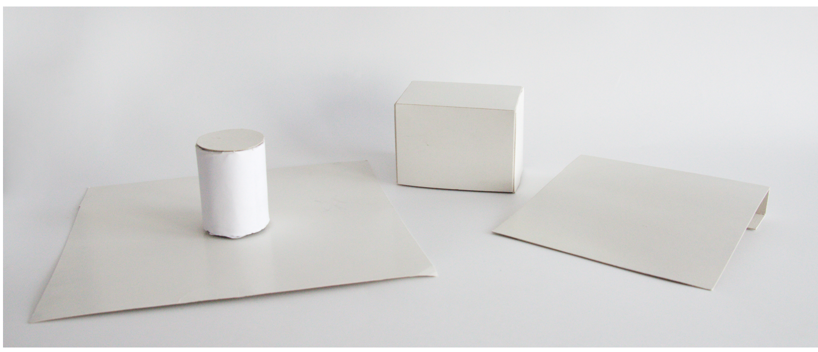

Figure 7.3: Paper-based prototypes used to evaluate, which interaction is the most suitable for each device.

Results: The most preferred and thus implemented gestures are highlighted in bold in Table 7.1 and shown in Figure 7.4.
For the *Graspable* device, participants preferred a click to start or stop a song (89%). For next/previous tilting the device was stated to be the preferred interaction by most participants (83%). Finally, to change the volume participants opted for turning the knob as known from many stereos (67%).
Concerning the *Touch* device, participants were undecided whether a one-finger tap or two-finger tap was best to start and stop the music. However one of both taps was selected by 77% of our participants as their favorite gesture. Similarly, participants were undecided concerning a one- or two-finger left/right swipe for next/previous, but overall liked the swiping gesture (94%). Accordingly they either picked a one- or two-finger swipe up/down for volume control (67%). These findings are in line with Wobbrock et al. who also found "that users rarely care about the number of fingers they employ" [260]. Thus we decided to support both, one- and two-finger gestures for all three commands.
For *Freehand* interaction, participants liked the vertically oriented hand to stop the music (67%). As counterpart – to start a song – we originally intended a thumbs-up gesture. How-

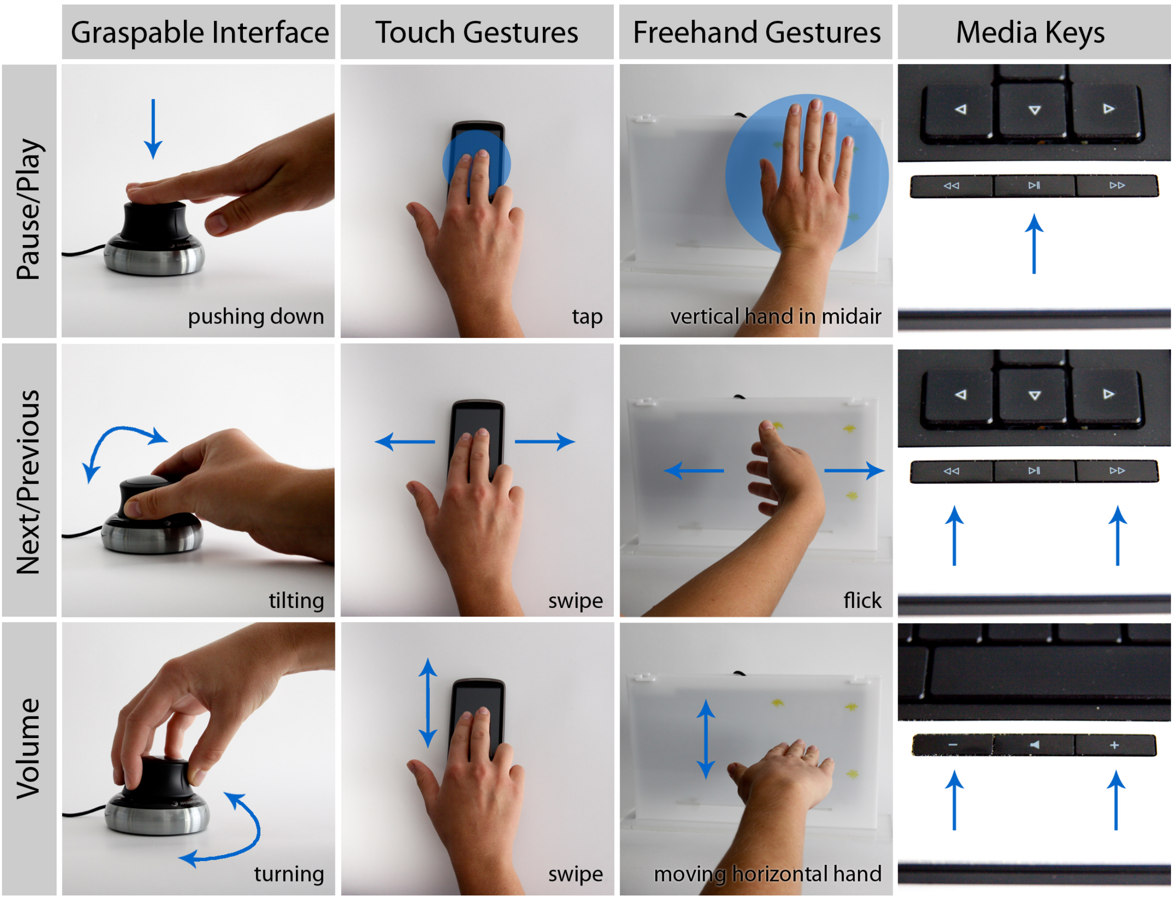

Figure 7.4: Interaction styles and their respective interaction derived from the paper-based study.

ever, this gesture was not very well received. Instead they suggested to also use the vertical hand for play, which we did. For skipping songs, participants preferred the flick gesture (78%). Last but not least, for changing the volume, moving the horizontally oriented hand up and down was liked by half of our participants (50%).
In the final questionnaire, participants stated that they would like to use a distinct device to control their music player at home (*median* = 4 on a 5-point Likert scale from 1 = totally disagree to 5 = totally agree). They expected that interaction would be easier (*median* = 4) and that they would enjoy it (*median* = 4). Eight participants (44%) picked freehand interaction as their favorite interaction style, seven (39%) preferred touch and finally three (17%) opted for the graspable interface.

Implementation

Having found gestures, we selected suitable hardware for the prototypes.

Hardware: For each peripheral device – graspable, touch and freehand – we had to find different hardware (cf., Figure 7.4). When possible, we opted for commercial products to ensure best possible tracking and reliability during the in-situ deployment.
The *Graspable* device is based on the Connexion SpaceNavigator (originally a 3D mouse), which offers six degrees of freedom. Pushing down the knob starts or pauses a song. Next/previous song was implemented as lateral push as well as tilting the knob. Rotating the knob changes the volume continuously (hence every 60 ms it is decreased or increased). All commands include a threshold to avoid accidental execution.
For *Touch* input we evaluated different touch pads but had to rule them out as they either did not offer a generic mouse driver or raw data access to decouple the touch pad from its original functionality of steering the mouse. Hence we opted for the touch sensitive surface of an Android Nexus One mobile phone. To mimic a generic touch service the display was set to black and the phone never went to sleep. Communication between the mobile phone and the computer was established through UDP. Hence, the cable connection to the USB port was only for power supply. Again we included a threshold, so that swiping gestures would not be interpreted as taps.
Freehand interaction was tracked with the help of a preproduction prototype[3]. The capacitive sensing device consists of five sensors (one in each corner and one in the middle) and offered the X, Y and Z-coordinate of the intruding hand's center in the electrical field. The available API already supported flicking gestures for next/previous and tap for pause/play. We implemented volume control as movement of the hand along the Y-axis. The box (Height $\times$ Width $\times$ Depth: 19 $\times$ 31 $\times$ 3.5 cm) with the tracking area (Height $\times$ Width: 7.5 $\times$ 10 cm) was easy to put on a desk and tracked a range of about 10 cm. This was suitable for our study, as it offered and easy setup and limited the interaction space, thus minimizing false positives.
To support *Media Keys* we used the Cherry EASYHUB MultiMedia keyboard, which offers grouped and exposed media keys. Volume control is located below the space bar and

[3] The manufacturer prefers to stay anonymous for strategic reasons.

next/previous and pause/play below the arrow keys. The media keys could all be accessed without any additional key presses such as function keys.

Software: The software is implemented for Windows in C# and connects the hardware and the audio player. As audio player we selected iTunes as it offers logging all interactions with the player. The GUI of our prototype was only used for closing the application. An icon in the system tray informed the participants that the application was running.

7.1.3 Procedure of the In-Situ Deployment

For the interaction to blend into the periphery, we decided to evaluate the Music Controller in an eight week in-situ deployment. All reported medians are based on 5-point Likert scales (1 = I totally disagree to 5 = I totally agree).

Participants

Overall eight participants (two female) took part in our study ranging in age between 21 and 31 years (average age was 25). Six of them were students and two were working. All of them used Windows and iTunes before the study. Three had media keys in their current setup but two of them had to press additional function keys to access them. Two others previously had media keys and missed them now. Moreover, four had keys to control the volume. All participants used the prototype at home, thus many different tasks were carried out while listening to music ranging from leisure (e.g., browsing the web) to working (e.g., for university). Of course, participants were free to use their computer and iTunes in every way they liked during the in-situ deployment, thus they could also leave their computer while listening to music. We just asked them to have logging turned on whenever their computer is turned on. Based on their rather technical background, all our participants spend much time at the computer. Although this might not be true for all potential users of such a system, this helped the study, as participants had more time to familiarize themselves with the devices during the in-situ deployment.

Seven of our participants stated to listen to music daily for about one to four hours. The other person listens to music about three to four days a week. They stated to spend about half of the time (51%) at their computer while music is turned on. Usually they select an album or a playlist and skip songs that they do not like ($median = 4.5$). Overall they rated their interaction frequency medium ($median = 3$). Mostly they use pause/play ($median = 3.5$), followed by volume ($median = 3$) and next/previous ($median = 2.5$). They wish for faster interaction ($median = 4$) and are bothered by the imposed focus switch when interacting with the player ($median = 4$), which they consider distracting ($median = 4$). However, apart from the focus switch, interaction with the mouse and the audio player's GUI is not mentally demanding ($median = 1$).

Procedure

During the eight week deployment, all participants tested all four interaction styles – the three peripheral devices (graspable, touch, freehand) and the media keys – each for two weeks (repeated measures design). We counterbalanced the distribution of devices (i.e., Latin square design) to minimize learning effects. During these eight weeks we carried out five semi-structured interviews and logged the following data: (1) *when* and *which command* (next/previous, pause/play, volume) was carried out, (2) *which interaction style* was used for interaction (one of the peripheral devices, mouse or media keys), (3) whether iTunes was *in focus* during interaction and (4) the *duration* iTunes was opened and music was played.

During the eight weeks we met five times with each participant:

1st Meeting: During the first meeting we interviewed our participants about their listening habits, how they usually interact with their audio player and collected demographic data. Afterwards we installed the application, set it to auto start, handed them their first device and introduced them to the gestures. At that point they did not know, which other devices they will be testing in the upcoming weeks.

2nd to 4th Meeting: The following meetings took place every two weeks. We interviewed the participants about their experience with the device. How they used it, how they perceived the mental load when interacting and if they felt that they could carry out the interaction in the periphery. At the end of the meeting they handed back the already tested device and were equipped with a new device and introduced to it.

5th Meeting: During the final meeting we once again asked about the device they tested during the previous two weeks. Afterwards we carried out a comparative interview about all devices. Eventually we uninstalled the software and collected all devices.

7.1.4 Results of the In-Situ Deployment

Over the course of eight weeks we collected qualitative and quantitative data. However, during an eight week in-situ deployment unexpected events occur. Thus one participant went on a spontaneous holiday and we had to exclude his data from the quantitative evaluation, while another participant in between switched jobs and consequently only was at home during the weekends for the last four weeks where he used the devices.

On average, each device was tested for the following number of days by each participant: graspable: 14.4 days, touch: 13.1 days, freehand: 12.8 days, and media keys: 15.1 days. For analysis we defined a listening session as listening to music without a break longer than 30 minutes [268]. We were able to log 391 of such sessions, which in total are 12 days, 5 hours, 32 minutes and 2 seconds of music being played. The longest listening session lasted 6:48:40 hours, however the average listening session lasted 45:03 hours. Overall the participants listened to 5652 songs (average of 14.5 songs per session) and executed 6119 commands including all interaction possibilities, thus peripheral devices, mouse and media keys. This offers an ample foundation for analysis.

Frequency of Use

The probability of issuing a command during one minute of music being played is the highest for freehand gestures (m = 92.9%, sd = 58.0%), followed by touch (m = 71.9%, sd = 26.4%), graspable interaction (m = 50.5%, sd = 26.3%) and finally media keys (m = 20.5%, sd = 24.7%). This data includes all possible input styles, thus not only the peripheral device but also mouse interaction and if available on their standard keyboard also media keys. Figure 7.5a also shows the probability of issuing a command for just the peripheral device or mouse interaction. Additionally we looked at the data individually for the first and second week with each device, however we did not find any significant change. Sometimes participants interacted more and sometimes they interacted less in the first week compared to the second week. Hence we believe that this is due to external circumstances and not related to the devices.

During the eight weeks deployment participants of course were free to interact with their preferred device, which included the peripheral device they were currently testing, their mouse and the regular iTunes GUI as well as the media keys if their standard keyboard provided them. We performed t-tests and found that all peripheral devices (graspable, touch, freehand) were significantly more used than the mouse and traditional iTunes GUI during the deployment (t-tests: graspable vs. mouse $p = 0.003$; touch vs. mouse $p = 0.003$; freehand vs.

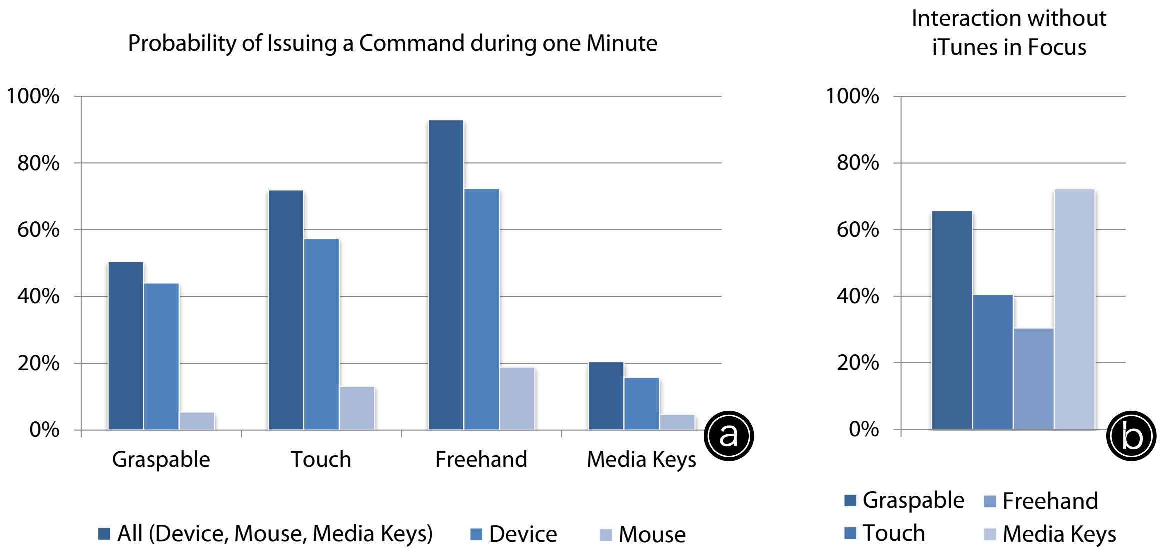

Figure 7.5: Quantitative results for the Music Controller: (a) probability of issuing a command during one minute and (b) interaction without iTunes being in focus on screen.

mouse $p = 0.006$). Thus our participants preferred using the peripheral devices for interaction in comparison to the traditional input via mouse.

Usage of Periphery

All devices (graspable, touch, freehand) were designed to be used in the visual and attentional periphery. Participants stated that familiarization was quick for all interaction styles (graspable: *median* = 5; touch: *median* = 5; freehand: *median* = 4.5; media keys: *median* = 4.5) although the location of the media keys and the freehand tracking was not immediately obvious to our participants. Gesture sets were considered to be clear for all peripheral devices (graspable: *median* = 5; touch: *median* = 5; freehand: *median* = 4.5), however media keys only received a medium rating (*median* = 3) as they required a targeted key press and the location of each key had to be remembered, although the keyboard layout of our test keyboard already emphasized them by the distinct location. Overall interaction only imposed minimal mental load for the peripheral devices (graspable/freehand/touch: *median* = 5) but more mental load was required to interact with the media keys (*median* = 2.5). Last but not least, disruption from the primary task was lowest for graspable interaction (*median* = 4.5) followed by touch (*median* = 3.5) and freehand interaction and media keys (both *median* = 3). The distribution of answers for all questions is depicted in Figure 7.6.

Apart from the subjective ratings we logged whether interaction with the device was carried out without iTunes in focus on the computer's display. This was generally possible for all peripheral devices and for media keys but of course not for mouse interaction. As Figure 7.5b shows, most interactions without having iTunes in focus have been carried out with media keys (m = 72.2%, sd = 11.8%) and through graspable interaction (m = 65.7%, sd = 16.9%). When using touch (m = 40.6%, sd = 13.0%) and freehand gestures (m = 30.4%, sd = 20.1%) less than half of the interactions have been carried out without iTunes in focus. Concerning freehand gestures, participants explicitly stated that they enjoyed observing the volume slider as it felt "magical". This of course is the contrary of what we want to achieve with peripheral interaction. However, we believe this effect is mostly based on the novelty effect and will fade once people are used to freehand interaction. In general, compared to mouse interaction, which always requires iTunes to be in focus, these are still good number. We also asked participants about their subjective rating for being able to interact without looking at the device. They also felt that graspable interaction worked well for them (*median* = 5). Furthermore they felt that touch was also easy to operate without looking at the device (*median* = 4). However, freehand gestures and media keys were both rated worse (*median* = 2.5) (cf., Figure 7.6).

Feedback

The use case of audio player control includes functional feedback [253], for instance the participants could hear when music started or stopped or the volume was changed. Participants stated for most devices to not miss any additional feedback (graspable: *median* = 5; media

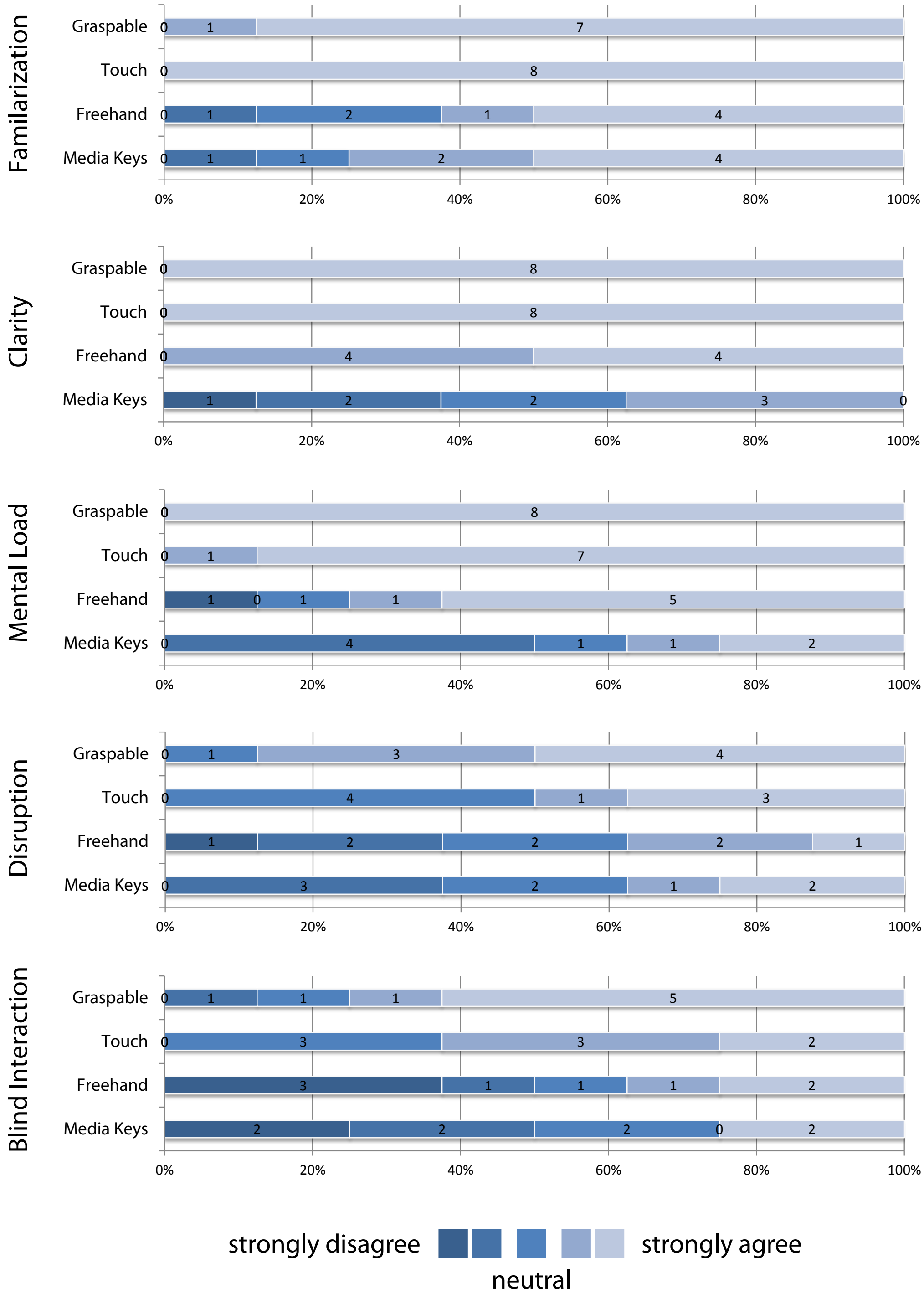

Figure 7.6: Subjective results (5-point Likert scales) for (1) short familiarization; (2) clear gesture sets; (3) low mental load during interaction; (4) low disruption during interaction; and (5) interaction without looking at the device.

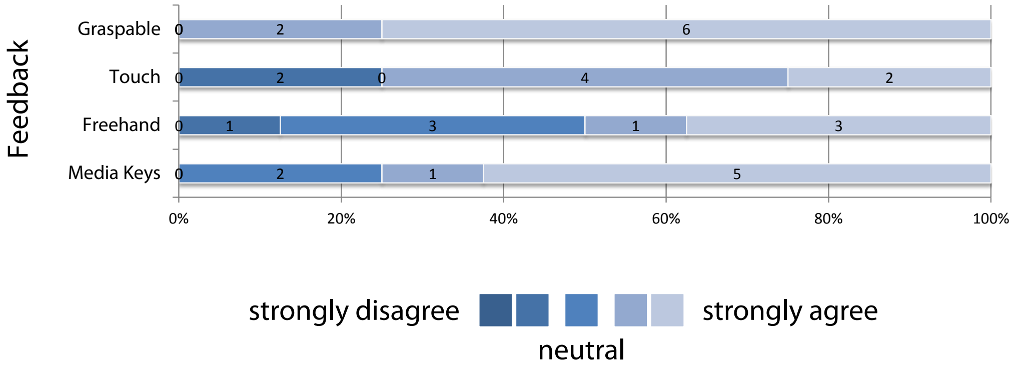

Figure 7.7: Subjective results (5-point Likert scales) for "no additional feedback necessary".

keys: *median* = 5; touch: *median* = 4; freehand: *median* = 3.5) (see Figure 7.7). As freehand gestures lacked physicality it was considered to be the interaction style with the least feedback (seven participants). Graspable interaction in contrast offered the most feedback (six participants).

Location of Devices

All our participants were right-handed and were free to position the devices whereever they felt comfortable (with the exception of media keys, which had a fixed location on the keyboard). For the graspable interface five participants positioned it on the right side while two used the left side. One participant changed the location frequently. All participants interacted with the respective hand. The touch device was located on the right by three participants and on the left by other three participants, all interacted with the respective hand. Two participants actually never used it on their desk, but as the cable connection was only needed to charge the device they carried it around and used it with their right hand as remote control. Two other participants also stated that they liked the possibility of carrying it around. This use case however was originally not intended by us. The freehand tracking device was located on the right side by seven participants. Apart from one participant, who used the left hand for interaction, all of the others interacted with the right hand. One participant changed the location and thus the interacting hand frequently. Media keys usually were pressed with the right hand, but occasionally the left hand was also used.

General Remarks

Overall participants considered the extension through the devices positive (*median* = 4) and enjoyed to control iTunes independent of the current system state (*median* = 5). For each device they named strengths and weaknesses. The freehand tracking device was considered to be too big, but futuristic and playful. The touch sensitive surface needed to be correctly oriented, hence for future implementations one could tilt the device (similar to current touch pads) or include tracking of the finger orientation [246]. However, participants enjoyed that touch could be used remotely. Graspable interaction was considered to be harder to achieve with the non-dominant hand than touch and freehand. But it was stated to be very ergonomic and similar to the mouse. Media keys required a precise key press, however no additional device was needed. Our participants reported that they could imagine to use the peripheral devices for further commands such as opening the player, activating shuffle or generally to control other applications.

7.1.5 Lessons Learned

The Peripheral Music Controller comprises three different interaction styles – graspable interaction, touch and freehand gestures – to offer peripheral interaction. This is the first prototype exploring touch for peripheral interaction and additionally the first project to compare all three interaction styles, for one use case.

Summary and Limitations

Table 7.2 summarizes the most important results of our eight week in-situ deployment. We found that overall all peripheral devices were well received. Although participants were free to use the mouse to interact with the audio player, most of the time the peripheral device was used. All devices were stated to impose only minimal mental load and could be used without iTunes in focus, however this was mostly the case for graspable interaction but less for touch and freehand gestures. While the task itself contained functional audio feedback, the inherent haptic feedback was less for freehand gestures as physical contact is obviously missing when interacting in midair. Familiarization for all devices was quick, however, for freehand gestures it took our participants a bit longer as the tracking area was not immediately clear. For all devices we found a preference for the dominant hand, however, each device was also used by at least one participant with the non-dominant hand.

In summary one can state that all interaction styles – graspable, touch, and freehand – could be successfully applied to peripheral interaction. However, especially freehand interaction

Table 7.2: Characterization of all peripheral input styles. One "plus" is a medium score.

		Graspable	**Touch**	**Freehand**
Usage:	**Preference over mouse and GUI**	+++	+++	+++
Periphery:	**Little mental load**	+++	+++	+++
	Interaction without focus on GUI	+++	++	+
Feedback:	**Inherent haptic feedback**	+++	++	+
Learnability:	**Easy familiarization**	+++	+++	++
Location:	**Preference for dominant hand**	++	++	++

still ranked a bit worse in some cases. This is probably due to the different development stages of the prototypes. While we tried to use commercial products to ensure reliability the graspable knob was still by far the most reliable device. The freehand recognition for flicking gestures was also pretty good, however, the other gestures were recognized less reliable. This might attribute to the higher interaction frequency for freehand gestures (false positives) and might also have affected subjective ratings.

Generalizable Findings for Peripheral Interaction

The Peripheral Music Controller investigated three interaction styles – graspable, touch and freehand – for the use case of listening to music and controlling the basic functions of an audio player. Similar to the previous projects, this of course only addresses one distinct use case and only one prototypical implementation for each interaction style. However, we can derive some findings, which we believe can be generalized.

Lower Interaction Barrier: Peripheral interaction can lower the interaction barrier. Participants interacted much more with the audio player during the weeks with the peripheral devices compared to the two weeks with the media keys (this includes all interactions, thus also mouse interaction with the audio player). This might be partly based on the novelty effect and the fact that the peripheral interfaces were more innovative. However, this happened for all three peripheral devices over the deployment of eight weeks. Thus, we believe the novelty effect alone cannot be the only answer. Participants stated that commands now were much more accessible and interaction was faster, easier and more comfortable. One can argue how much interaction is necessary while listening to music, and if more interaction might not actually be more disruptive. But applied to other use cases, which address tasks that might often be neglected (cf., StaTube's state management in Chapter 6.1), lowering the interaction barrier can be very beneficial.

Decoupled Devices: In contrast to the media keys, which were located on the keyboard, the peripheral devices were additional devices decoupled from the usual input devices. This offered new ways of interaction, such as carrying around the touch device and using it as remote control, which was very much enjoyed by the participants. However, participants also stated to like that they did not need an extra device on their desk during the deployment of the media keys. Future prototypes could be integrated into current hardware, for instance touch pads in notebooks could be used as well as integrated web cams for vision based freehand tracking. However, new problems might arise as in this case users explicitly have to state that they now want to use these input channels for their peripheral input instead of their regular usage. As related work showed, people – even very experienced users – are not good at using keyboard shortcuts [147] and we also found in this study, that media keys were used much less than the peripheral devices. Hence we believe that one should not rely on additional keys or keyboard shortcuts for peripheral interaction or even to initiate peripheral interaction (e.g., switching the mode of the touch pad). Moreover, future technology will probably be more miniaturized and could be integrated in furniture, such as desks, and thus not be considered as separate and additional device anymore.

Learning and Habituation: Similar to the previous projects we again saw that the interaction itself is very simple and straightforward (e.g., flicking, swiping) and familiarization was generally quick. However, the shift to the periphery had to be learned. It seemed to be easier for interaction styles that were already more known such as graspable interaction, which was compared to mouse interaction and touch, which is very common on mobile devices. For freehand interaction, especially finding the tracking area, took some more time. However, the biggest challenge again was breaking loose of old habits (such as pressing alt+tab to switch to iTunes) and adapting new habits. Participants stated that even though they switched devices every two weeks, the process of learning to actually use a peripheral device and thus the periphery of their attention for interaction progressed through the weeks independent of the device.

Feedback: Overall our participants were satisfied with the feedback they received although we did not add any additional feedback. However, the task of controlling an audio player already includes functional feedback. Moreover, especially if there is physical contact to the device, such as for graspable interaction and to some extent touch interaction, participants feel assured in their interactions. As freehand tracking most likely will get more reliable in the future and people will get more used to interacting with freehand gestures, the lack of physicality might be less problematic.

Location of Device: Related work in the field of peripheral interaction did not yet assess, which hand works better for peripheral interaction. While we also did not directly assess that, we observed that there is a general preference for interaction with the dominant hand. This on the one hand is not surprising as our motoric capabilities are better with our dominant hand. On the other hand interaction is usually really simple and for example touch gestures can be performed equally well with the dominant as well as the non-dominant hand in terms of speed and errors [11]. Additionally, while working on the computer, the dominant hand is often occupied by the mouse. Thus the non-dominant hand would be free to interact. Annett and Bischof thus suggest to encourage users to also use their non-dominant hand for interaction as this might "increase productivity and [...] also input bandwidth" [11]. Overall, participants stated, that comparing all devices they tested, graspable interaction was the hardest to achieve with the non-dominant hand, as it required grasping the device while interacting.

Measuring Periphery: Measuring how much an interaction moves to the periphery is a hard task. While a lab study offers many possibilities to observe participants or equip them with for instance eye-trackers the setting is artificial and the participants are usually very focused on their tasks, thus it is very unlikely that any interaction will move to the periphery. On the other hand, in the field, observation is limited and for privacy reasons one has to limit logging (e.g., logging the primary tasks, all open windows etc. is too invasive). Still, one can implement weak indicators such as the focus of the application the peripheral device is connected to. However, as stated this is only a weak indicator, as iTunes might still be visible in the background or on a secondary screen during interaction and would still be logged as iTunes being out of focus.

Extended Design Space: While of course every interaction style has its advantages and drawbacks we conclude from this evaluation that touch and freehand interaction can be successfully applied to peripheral interaction alongside graspable interaction. Participants preferred the peripheral devices over the mouse for all conditions. Depending on the use case, for instance there might be no space for a graspable device or hygiene regulations might prevent interaction through touch, one of the different interaction styles can be selected.

7.2 Exploration: Interaction Styles & Feedback

Interaction Style & Feedback[4] [107], offers a second study, which investigates all three interaction styles – graspable, touch and freehand – and also additional visual feedback, which was not incorporated in the Peripheral Music Controller.

Interaction Styles & Feedback, in contrast to previous work, is evaluated in the lab. This of course comes with some drawbacks, for instance participants only have a limited time to familiarize themselves with the prototype. However we are able to observe participants more closely while interacting (Chapter 9 discusses evaluation for peripheral interaction – especially lab vs. in-situ – in more detail). When evaluating in the lab, participants do not interact based on intrinsic motivation (e.g., skipping a song because they do not like it) but their interaction has to be triggered. Thus we selected the use case of email sorting as the peripheral task. Many people receive a notification about each new email often including the sender and the subject of the email. From this little information one can often already determine if an email is of immediate interest or spam and can be deleted [239]. Thus our prototype supports immediate interaction with such notifications to for instance delete an email (see Figure 7.8). All interactions are available via a graspable interface, touch and freehand gestures. Additionally different feedback about the interaction is given.

Interaction Styles & Feedback in the Design Space

Referring back to the previously developed classification, Interaction Styles & Feedback is again designed to offer peripheral interaction while engaged with a digital primary task on the desk (see Figure 7.9). Interaction with Interaction Styles & Feedback is explicit through one of the investigated interaction styles – graspable, touch or freehand – thus interaction is

[4] Chapter 7.2 is based on: Hausen, D.,Wagner, C., Boring, S., and Butz, A. *Comparing modalities and feedback for peripheral interaction.* In Extended Abstracts on Human Factors in Computing Systems (CHI), ACM, 2013, 1263-1268.

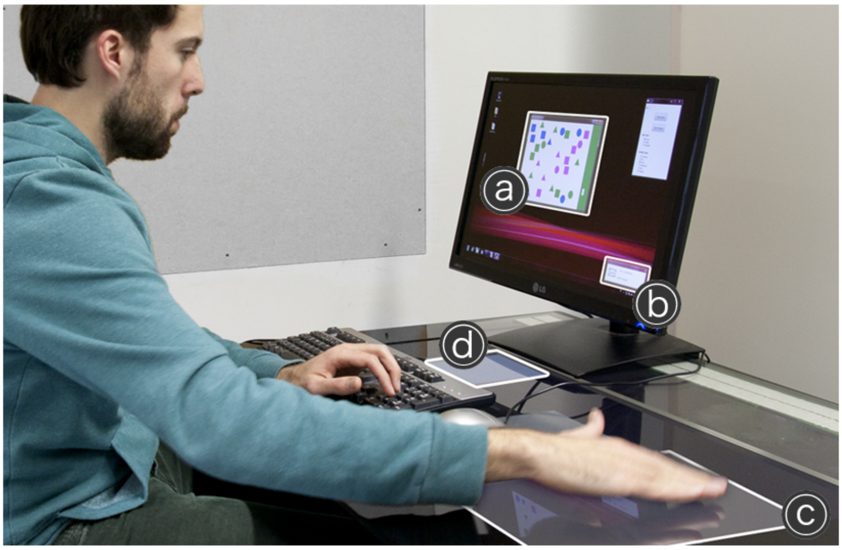

Figure 7.8: Participant during the study: (a) the primary task occupies the participant's attention and hands; (b) the email notification triggers the secondary task; (c) the interaction area; and (d) the feedback area.

Primary Task	Physical		Digital
Explicitness	Implicit		Explicit
Input	Gaze	Speech	Bodily
Proximity	Close		Distant
Granularity	Low	Medium	High
Privacy	Public	Personal	Private
Feedback	Inherent	Functional	Additional

Figure 7.9: Interaction Styles & Feedback located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by Interaction Styles & Feedback.

at arm's length and consequently rather close by. Overall four commands can be executed leading to low granularity. Emails can be considered as private information. Based on the interaction styles inherent haptic feedback is provided. The task itself offers visual functional feedback for one command (directly show new email on screen) and additional visual feedback for all commands.

In terms of the task-based perspective, Interaction Styles & Feedback is system-driven as the interaction is triggered by notifications from the system and supports an additional task, as reacting to an incoming email is usually not the current primary task. Finally, the prototype and its use case offer retrieval of data (e.g., showing the incoming email on screen) but also manipulation (e.g., deleting an incoming email).

7.2.1 Background: Email Management

Venolia et al. [239] distinguish five different activities that are performed when dealing with emails: *Flow* (monitor incoming email), *Triage* (dealing with emails after a longer period of absence), *Task Management* (emails as reminder), *Archive* (storing emails) and *Retrieve* (accessing achieved emails). Our prototype addresses "Flow". However, we are not interested in the type of notification (e.g., ambient displays for monitoring mails [121]) but want to offer direct interaction right after the arrival of a notification. The information provided in a notification window about an arriving email usually is enough to decide whether one wants to read or delete it [239]. Even though sending an email is usually considered to be less disruptive than calling a colleague, because new emails do not require an immediate reaction, most users still do react immediately [132]. To counteract immediate reactions and stay focused on the current primary task, people are sometimes advised to turn of the notifications. However, research showed, that turning of the notification often increases self-interruption to actively check for new emails [127]. To reduce the impact of notifications and the subsequent reactions, we consider peripheral interaction a well fit for carrying out such immediate reactions.

7.2.2 Designing and Building Interaction Styles & Feedback

For all three interaction styles we offered four commands to immediately react to emails and designed different feedback types for each of these commands.

Functionality

We wanted to design the four interaction styles as comparable as possible, thus we opted for the four cardinal directions to encode the four most common actions on new emails (see Figure 7.10). Based on metaphors (expecting the interaction area being on the right of the keyboard) we mapped the four commands to the four directions: *down* to delete an email (cf., throwing it into the trash bin), *right* to mark as read (cf., pushing something away), *up* to flag as important (cf., being on top indicates importance) and *left* to display an email on the computer's display (cf., bringing something closer to oneself). Thus, for touch and freehand gestures, the users have to swipe on the desk or wipe above the desk in the corresponding direction to interaction. To keep the graspable device comparable, we designed a tiltable device (see Figure 7.11) that can be shifted in four directions (and returns to the initial position on its own).

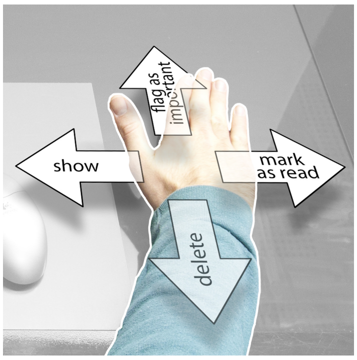

Figure 7.10: Four directions for four commands related to emails

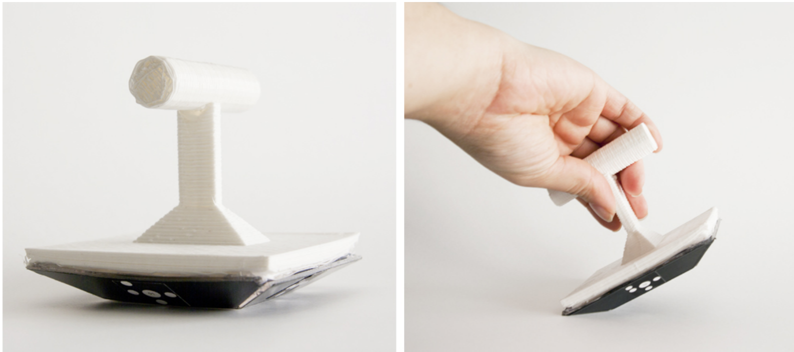

Figure 7.11: Graspable/Tiltable device printed on a 3D printer and equipped with markers. After tilting it, the device returns to its initial position on its own.

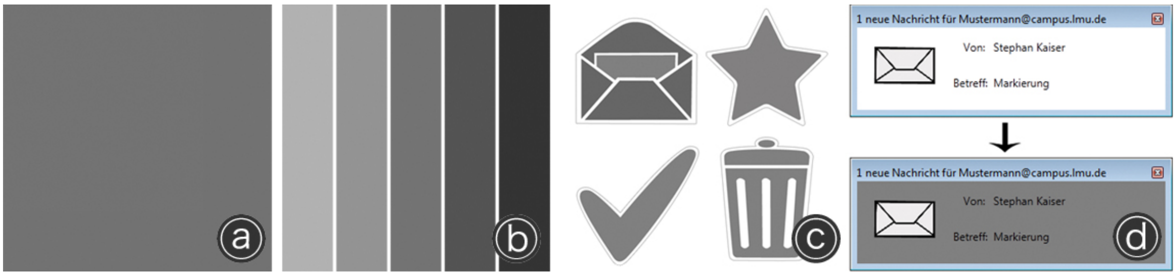

Figure 7.12: Feedback types: (a) *Binary*: feedback area changes color upon interaction, (b) *Animation*: animation in the feedback area indicates which direction was tracked, (c) *Symbolic*: symbol indicates the triggered action, (d) *Notification*: the notification (i.e., the original email notification shown on the display where the primary task is performed) is colored when an interaction is tracked, and *None*: No feedback is shown.

Feedback

As our previous prototypes primarily relied on inherent and functional feedback this project explicitly incorporates additional feedback. While auditory feedback seems to be promising for peripheral interaction [24] we deliberately opted for visual feedback, as auditory feedback might not be suitable in the office context as nearby colleagues might be disturbed by it. In the spirit of ambient information, we intended the feedback animations to reside in the periphery, which should not have any negative effect on task performance [170]. Overall we evaluate five different feedback types differing in the location and the presented level of detail (an interaction was recognized or more detailed, which interaction was recognized) (see Figure 7.12). As feedback area we selected the space between display and keyboard, as users will be able to see it in the visual periphery while focusing on the display. As second location we selected the primary display, as the users' focus is most likely already there. Feedback types are *Binary* (feedback area changes color), *Animation* (an animation in the feedback area indicates tracked interaction), *Symbolic* (each command is represented by a symbol), *Notification* (the notification is colored upon an interaction) and *None* (no feedback at all). All feedback conditions were designed in grey to avoid bias through individual color preference. Last but not least, when requesting the email to be shown (interaction to the left), functional feedback was present as the email appeared on the computer's display.

Implementation

The system is implemented on a Samsung SUR40 tabletop, which is extended with a traditional computer display, mouse and keyboard. The tabletop's display is set to black to resemble a traditional desk and acts as sensing device for touch and freehand interaction as well as for the marker tracking of the graspable device. Additionally the feedback is displayed on it between the regular display and the keyboard (feedback area sized 300 $\times$ 300 px, 14 $\times$ 14 cm) (see Figure 7.8d). The interaction area (sized 700 $\times$ 500 px, 32 $\times$ 23 cm) is located on the right of the keyboard and mouse (see Figure 7.8c). The graspable device was designed in Autodesk 3ds Max and printed on a 3D printer (see Figure 7.11). The handle makes it easy to grasp and helps to determine the correct orientation. By tilting the device, the corresponding tag is pressed onto the surface and tracked. We opted for tilting although for example moving the graspable device in one of the four directions might have been more in line with the wiping and swiping gestures, but the graspable then would not be at a fixed location and there might arise the need to reposition it before interaction.

7.2.3 Procedure of the Lab Evaluation

Most of the prototypes for peripheral interaction are evaluated through in-situ deployments (e.g., [26, 69, 101]) to offer participants enough time to get accustomed to the devices. Only Olivera et al. [189] investigated their prototype PolyTags (cf., Chapter 4.4.1) in the lab using a dual-task setup. As primary task they selected counting vowels in a text. This primary task aims at distracting the user and for assessing quantitative data about the distraction. As we wanted to mimic a regular desk setting we designed another primary task, which also occupies the hands similar to working on a computer. The design of the primary task is extensively discussed in Chapter 9, thus we here limit the description to its basic functionality.

Tasks

For a dual-task study we needed a primary and a secondary or in our case peripheral task.

Primary Task: Inspired by Square-Click [218], participants were asked to click on and thereby delete different shapes (see Figure 7.8a). The color on the right indicates, which colored shapes they are supposed to delete. While clicking, they also had to press a corresponding key on the number pad for each shape and color combination. Once all shapes in the given color are deleted, all other shapes disappeared, new shapes appeared and a new color was randomly chosen. This task hence occupies both hands – one on the mouse and one on the keyboard – and asks for continuous input. However, it also leaves room for the participants to decide when to interrupt and attend to the secondary task, for instance participants finished one round (deleting all shapes in the given color) before taking care of the secondary task. One round lasted about 10 seconds depending on the participant's individual speed.

Peripheral Task: As already stated, the peripheral task was sorting emails, which was triggered by notifications. Instead of the subject line the instruction about the interaction was given, for instance "delete" or "read".

Participants

We recruited 30 participants (14 female) ranging in age from 19 to 30 years (average age: 22). 63% of our participants use a standalone email client and 89% of those receive notifications about emails.

Experimental Design and Procedure

We applied a mixed-model design consisting of our three interaction styles (graspable, touch, freehand) as between groups factor (10 participants per group) and the five feedback types (binary, animation, symbolic, notification, none), which were tested by all participants and their respective interaction style. We counterbalanced the order of feedback to avoid learning effects. Each participant received 16 pop-up notifications for each interaction style and feedback combination, with at least 13 seconds in between them (to be able to finish one round in the primary task between two notifications). The notifications were displayed in the lower right corner and disappeared again on their own.

At the beginning we introduced the participants to the study and asked them to fill out a demographic questionnaire also rating their experience with the tested interaction styles. Afterwards we explained both tasks – the primary and the peripheral – to them and let them train both. Once they felt accustomed to both tasks we conducted a baseline measurement for the primary task (i.e., they interacted with the primary task without any interruptions. We used this data for later comparison. Afterwards we asked them to perform the primary task in parallel with the peripheral task and different feedback for five times (each round lasting five minutes). After each feedback condition a questionnaire was handed to them. Having finished all rounds, we introduced the two interaction styles that they did not test and let them try them and asked for their preference. Finally, the participants filled out a closing questionnaire.

We measured the *loss of performance* in the primary task (the number of clicked shapes in comparison to the baseline), the number of *errors* in the primary (wrong color or key press) as well as in the peripheral task (wrong or no reaction). Additionally, we calculated the *interruption lag* (time between stopping the primary task and starting the secondary task) and the *resumption lag* (time between finishing the secondary task and resuming the primary task). Additionally we collected subjective data through the questionnaires.

7.2.4 Results of the Lab Evaluation

To gain a deeper understanding of the influence of the interaction styles and the different feedback types we analyzed the quantitative and the subjective data.

Loss of Performance

Comparing performance in the primary task with the respective interaction style to the baseline, the loss of performance was highest for *graspable* interaction ($m = 18.2\%$, $sd = 7.9\%$) followed by *freehand* ($m = 9.2\%$, $sd = 13.2\%$) and *touch* ($m = 5.8\%$, $sd = 7.5\%$) (see Figure 7.13a). A one-way independent ANOVA revealed a significant effect ($F_{2,27} = 4.247$, $p = 0.025$) for interaction style. The Tukey HSD post hoc test showed that the performance in the primary task was significantly worse for *graspable* compared to *touch* ($p = 0.23$).

Analyzing loss of performance for different feedback types did not reveal any significant differences.

Error Ratio

Error ratio in the primary task was fairly similar for all three interaction styles: *freehand* ($m = 11.2\%$, $sd = 3.9\%$), *touch* ($m = 12.0\%$, $sd = 3.7\%$) and *graspable* ($m = 14.9\%$, $sd = 2.3\%$) (see Figure 7.13b). Thus we did not find any significant effect. The same holds true for different feedback styles.

Concerning the peripheral task we logged most errors for *freehand* interaction. This was mostly because positioning the hand was sometimes already interpreted as interaction (cf., the Appointment Projection in Chapter 6.2.4). However, overall the number of errors for

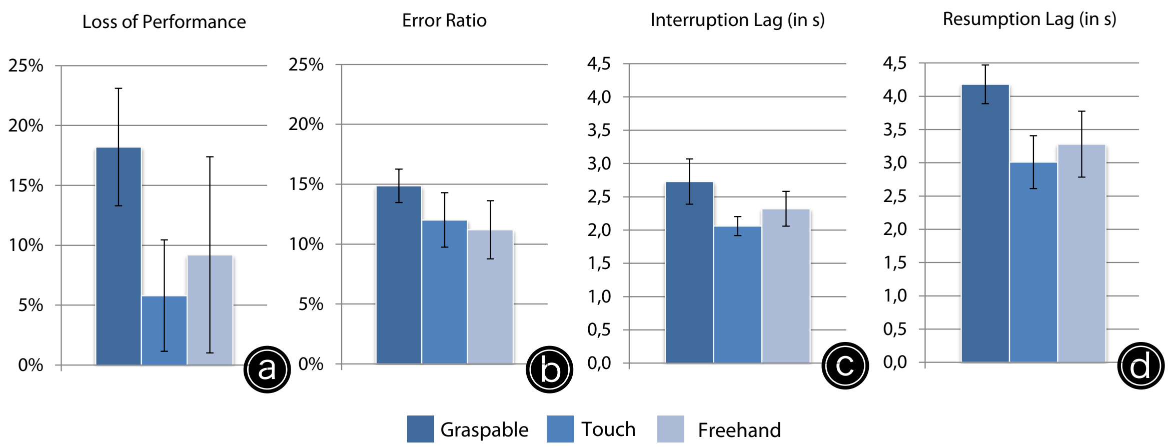

Figure 7.13: Quantitative Results: (a) loss of performance; (b) error ratio in the primary task; (c) interruption lag (in seconds); and (d) resumption lag (in seconds). Error bars are 95% confidence intervals.

each interaction style is below 5% (including events that were completely missed by the participants), thus we refrained from further statistical analysis.

Interruption and Resumption Lag

We calculated the interruption lag and found that it was shortest for *touch* (m = 2.06s, sd = 0.23s), followed by *freehand* (m = 2.32s, sd = 0.42s) and *graspable* interaction (m = 2.73s, sd = 0.55s) (see Figure 7.13c). We performed a one-way independent ANOVA and found a significant effect ($F_{2,27} = 6.150$, $p = 0.006$). The Tukey HSD post hoc test showed that the interruption lag for *touch* was significantly shorter than for *graspable* interaction ($p = 0.005$).

Similar to the interruption lag the resumption lag was shortest for *touch* (m = 3.01s, sd = 0.64s), followed by *freehand* (m = 3.28s, sd = 0.80s) and *graspable* interaction (m = 4.18s, sd = 0.47s) (see Figure 7.13d). Again a one-way independent ANOVA showed a significant effect ($F_{2,27} = 8.787$, $p = 0.001$). Based on the Tukey HSD post hoc test, *graspable* interaction caused a significantly longer resumption lag compared to both – *touch* ($p = 0.001$) and *freehand* ($p = 0.012$) interaction.

Again we did not find any significant effect for different feedback types.

Subjective Data

Subjective data was collected through 5-point Likert scales ranging from 1 = I totally agree to 5 = I totally disagree.

All interaction styles were considered to be easy to learn (all: *median* = 5). The interaction was not physical demanding (all: *median* = 1) and participants felt like they did not have to think much about it (all: *median* = 4). Generally, interaction difficulty was ranked rather low (*touch*/*freehand*: *median* = 2, *graspable*: *median* = 2.5), however participants felt that the primary task did suffer (*freehand*: *median* = 2, *touch*: *median* = 3.5, *graspable*: *median* = 4). For the distribution of answer refer to Figure 7.14.

Participants felt that feedback was important during the email sorting task (*touch*/*graspable*: *median* = 5; *freehand*: *median* = 4) and everybody stated to miss the feedback in the *None* condition, as they were not sure if their input was recognized by the system. Participants preferred feedback that also indicated the interaction that was tracked (e.g., *Animation*) in contrast to feedback that just indicated that an interaction was tracked (e.g., *Binary*) (*touch*: *median* = 5, *freehand*: *median* = 4, *graspable*: *median* = 3). This also reflects in the Condorcet Ranking (from most to least liked feedback): *Symbolic*, *Animation*, *Binary*, *Notification* and finally *None*. Overall participants did not feel distracted by the feedback (*Binary*: *median* = 1.5, others: *median* = 2) and in general paid moderate attention to the feedback (*median* = 3). Figure 7.15 shows the distribution of answers.

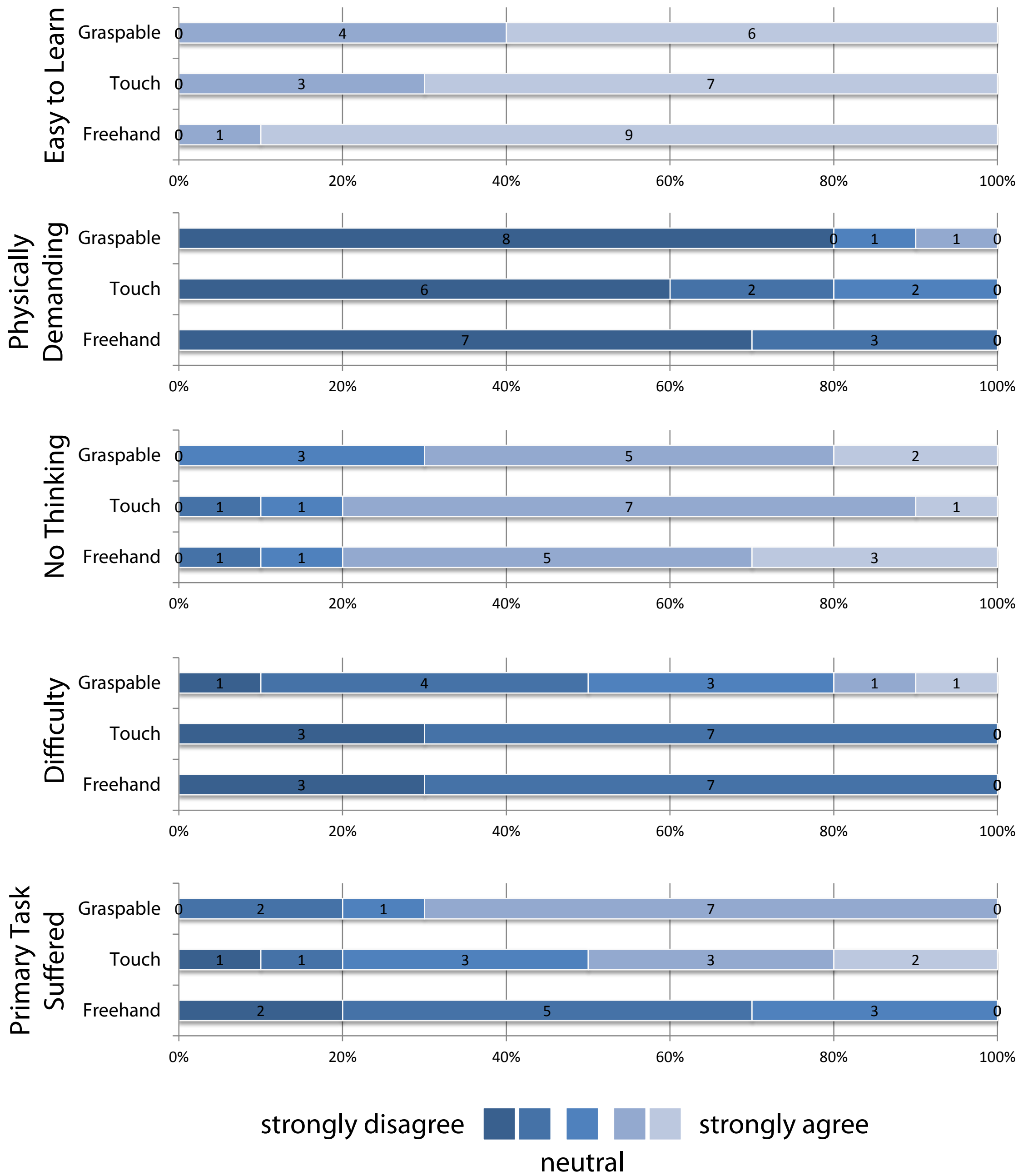

Figure 7.14: Subjective results on 5-point Likert scales for (1) interaction was easy to learn; (2) interaction was physically demanding; (3) interaction could be carried out without thinking; (4) interaction was difficult; and (5) the primary task suffered because of the peripheral task.

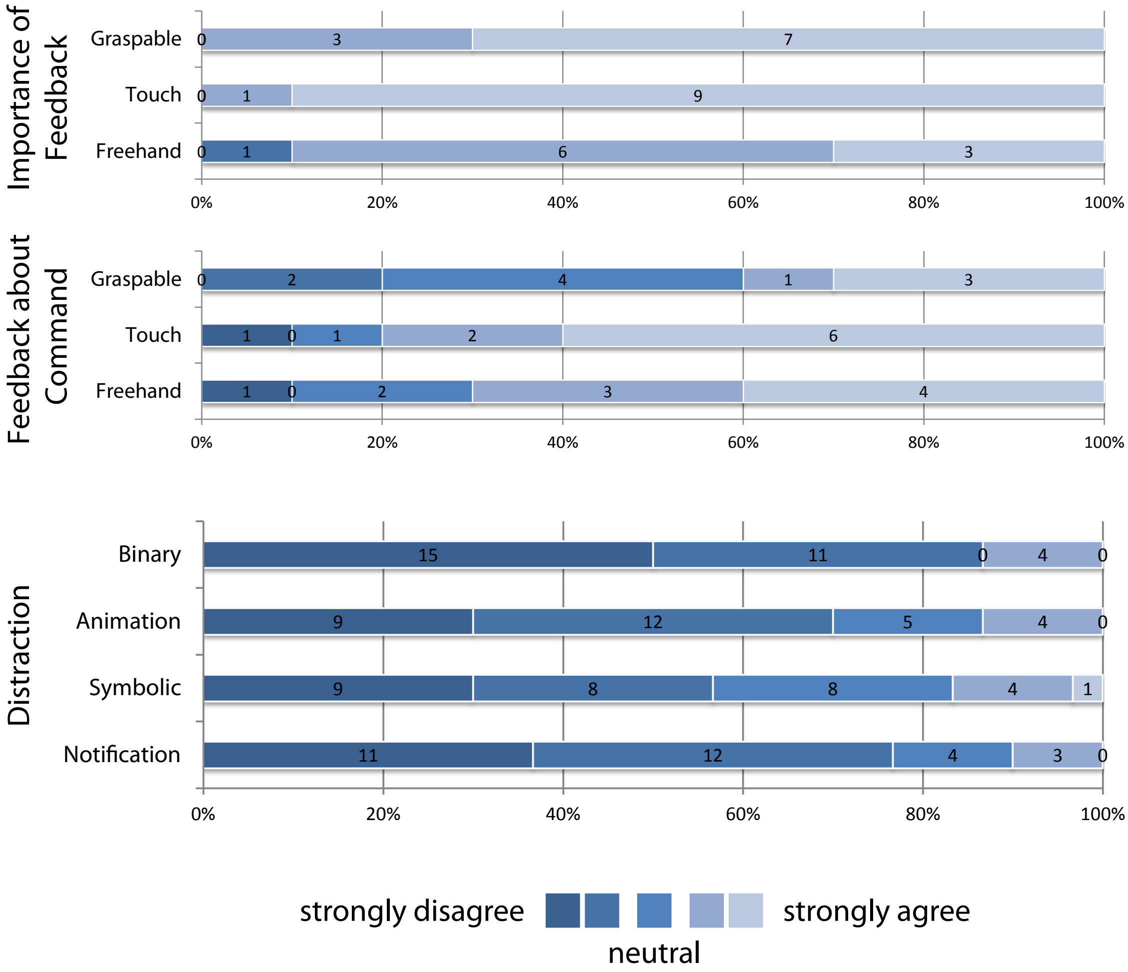

Figure 7.15: Subjective results on 5-point Likert scales for (1) having feedback was important; (2) feedback about specific commands was important; and (3) feedback distracted me.

7.2.5 Lessons Learned

With the Peripheral Music Controller (cf., Chapter 7.1) addressing only one use case (music control) with very specific characteristics (functional auditory and inherent haptic feedback only), Interaction Styles & Feedback offers a second view on the three interaction styles – graspable, touch and freehand interaction – and thereby offers (next to inherent haptic feedback) also functional visual feedback and additional visual feedback.

Summary and Limitations

Interaction Styles & Feedback investigates all three interaction style – graspable, touch and freehand – with the use case of email sorting. Based on the information presented in an email notification, users can immediately perform simple interactions for instance to delete or open an email. In a lab study we found that all peripheral interaction styles were generally fit for the task. Participants considered them to be easily learned and remembered and not cognitively demanding.

Concerning feedback we did not find any significant influence on any measured parameter. However participants argued for (even detailed) feedback. Based on subjective data the peripheral feedback on the desk (in contrast to on the computer's display) was preferred, but we did not find any measurable difference.

As this evaluation was lab based we have to remember that the results might slightly differ in a real world setting. The study did not take into account messy desks or movement of the arms above the desk, which is part of the working routine (e.g., grasping for a pen). Moreover we based our implementation on an interactive tabletop. To be working on standard desks, tracking needs to be adapted (e.g., through Leap Motion[5]). Additionally, feedback needs to be displayed by other means (e.g., enhanced keyboards [34] could display at least abstract feedback).

Generalizable Findings for Peripheral Interaction

Again we derived some more generalizable findings from this study concerning the three interaction styles, feedback and peripheral interaction.

Interruption & Resumption Lag: We calculated the interruption and resumption lag (cf., Chapter 2.1.2) and found that the interruption lag was overall shorter than the resumption lag. While the interruption lag is also used to convey the primary task in a safe state, the user also mentally switches to the peripheral task. Thus, the interruption lag being shorter than the resumption lag might indicate that less cognitive load is necessary to switch to the peripheral task.

Feedback: We did not find any quantitative measurable difference for all additional feedback conditions even compared to no feedback at all. However, participants strongly argued for it. In contrast, participants during the Music Controller study were quite happy with the feedback they received. Thus, functional feedback seemed to be working very well, but if neither functional nor additional feedback is present, participants – although they still performed the obviously simple interaction equally well – did not feel at ease. This was even true for the graspable condition here, although it offered more physical feedback than touch and especially freehand interaction. Thus, inherent feedback through our bodily interaction does not seem to be enough to trust that the interaction was successful. This is no new insight in human-computer interaction, however, for peripheral interaction, which aims at targeting as few cognitive resources as possible, offering feedback (functional if available, otherwise additional), which of course needs to be processed to some extent, still seems beneficial.

[5] https://www.leapmotion.com (Last Accessed: 28.06.2013)

Interaction Styles: In contrast to the Peripheral Music Controller, where the graspable device was preferred, we found here that the graspable device was least liked and also was outperformed by touch and freehand interaction based on quantitative measured data (loss of performance, interruption and resumption lag). We believe several reasons caused this effect: (1) In this project all three interaction styles were based on the same hardware, thus the recognition rate (for freehand interaction) was about the same as for all other interaction styles. (2) We offered bigger interaction areas for touch and freehand gestures in this prototype compared to the Music Controller. Thus, participants were able to pay less attention to correctly positioning their hand while interacting via touch or freehand. However, when reaching for the graspable device, they had to grasp more precisely. Nevertheless, for a real life deployment the size of the interaction area has to be fine-tuned (probably specifically for a given task, use case or setting) to avoid unintentional gestures. (3) While interaction with touch and freehand is rather straight forward in case of four cardinal directions, a graspable device can still look very different. We opted for tilting, but moving the device or turning it in the corresponding direction would also be possible. Thus we might just not have picked the optimal design. With the graspable device being very successful for the Peripheral Music Controller and other successful designs in related work, we believe that even though it was outperformed by touch and freehand interaction here, it can still be very successfully applied to peripheral interaction. However, in this case touch and freehand interaction outperformed the graspable device, which we consider as a strong indicator that generally touch and freehand interaction can work well for peripheral interaction.

Chapter 8

Exploiting Spatial Memory

Synopsis

Having compared graspable, touch and freehand interaction, this chapter explores touch and freehand interaction based on spatial memory in more detail. Two prototypes – the Unadorned Desk 2D and its successor the Unadorned Desk 3D – investigate how people place and retrieve virtual items in off-screen space. Virtual items could be anything assisting the primary or secondary task, for instance, stored commands to change the music or tools related to the current application such as brushes in a graphics editing program. Observed by a depth camera, the Unadorned Desk uses the available space left and right of mouse and keyboard as interaction area or volume. In overall three studies (two in 2D and one in 3D) we found that people are generally able to store and retrieve virtual items in off-screen space, even with no feedback and thus minimal visual attention. Participants relied on grid-like arrangements and preferred the bottom plane to vertical arrangements in 3D. Based on the experiments we found that items with a radius of 85 mm work best, however, if limiting the amount of items and relying on the best selection gesture (Dwell Time) item size can be reduced to a radius of 50 mm in 3D. We believe that applications designed based on our evaluated parameters can successfully support secondary tasks in the periphery, as they do rely on coarse interaction without requiring visual attention.

The previous projects incorporating touch and freehand interaction all relied on continuous and/or location independent gestures (as long as performed in the tracking area), such as swipes and taps for touch or flicks and wiping for freehand interaction. This chapter further investigates how spatial memory (cf., Chapter 2.2.2) can be exploited for peripheral interaction using discrete and/or location dependent interaction. Related work investigating peripheral interaction already indicates that spatial information can be helpful, as teachers in Bakker's et al.'s study with FireFlies [25] pointed out that arranging the students' names on the teacher tool according to the spatial arrangement of the seats in the room would have greatly helped them to find the correct bead.

In this chapter two manifestations of the Unadorned Desk – a regular desk just augmented with depth sensors for hand tracking – will be presented: The first exploring how people make use of a virtual two dimensional space on their desk through touch, and the second extending the interaction space into the third dimension and interacting in mid-air.

8.1 Exploration: Unadorned Desk 2D

In our physical daily life we easily retrieve artifacts based in our peripheral vision and spatial memory. For example while working on a desk, we reach for pens, coffee mugs and paper documents, without really looking and focusing our full attention on it. The Unadorned Desk[1] [100] wants to adopt this to digital data and investigates the physical space around the desk to store and retrieve digital artifacts. This is especially beneficial as computer screen space is limited. The screen on the computer is divided into the primary workspace (holding the current document), the secondary workspace (holding a subset of artifacts relevant for the primary task in form of tool palettes and icons) and the off-screen workspace (holding all remaining artifacts through menus, dialog boxes or other windows) (see Figure 8.1a). Commands, applications and tools, which are stored in the off-screen workspace can be costly to access in terms of time and efficiency [89]. Keyboard shortcuts, which could speed up the process, however, are very underused, even by expert users [147]. More commonly, users perform a series of operations to access these hidden artifacts or make them visible on screen. Thus, there is a trade-off between offering many artifacts on the secondary workspace for easy access but crowding the primary workspace.

To overcome this problem, the Unadorned Desk, only augmented with depth sensors, is designed to make virtual items (e.g., applications or commands) accessible through touching a distinct location on a desk (see Figure 8.1b). This interaction is inspired by our everyday lives were tools (e.g., brushes while painting or home improvement tools while crafting) are also retrieved from the periphery. We also again address the amount of feedback necessary for peripheral interaction, which in this case relies on spatial memory. However we refrained

[1] Chapter 8.1 is based on: Hausen, D., Boring, S., and Greenberg, S. *The Unadorned Desk: Exploiting the Physical Space around a Display as Input Canvas.* In Human-Computer Interaction (INTERACT), Springer, 2013, 140-158.

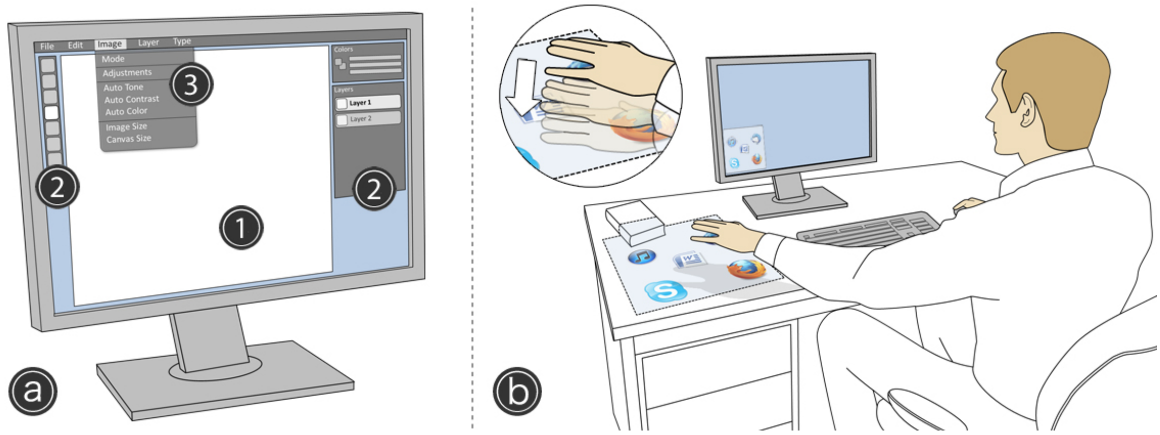

Figure 8.1: (a) The three workspaces present in the desktop metaphor: the primary workspace (1) holding the active document people work on; the secondary workspace (2) holding items related to the activities in the primary workspace and is permanently visible; and the off-screen workspace (3) holding further items, yet one has to make them explicitly visible (e.g., menus). (b) The Unadorned Desk moves virtual items (e.g., commands or applications) onto a regular desk, thus the periphery, freeing space on the display. When hovering over the interaction area on the desk, feedback may be given on-screen. Touching an item then selects it.

from offering projected feedback on the desk [143, 252], using a tabletop as desk to display feedback [31] or adding additional displays through tablet computers [31]. We only use feedback on the primary computer screen, most likely the current focus of the user, thus limiting macro attention shifts and augmentation and therefore building a system, which is easy to setup and could potentially be used everywhere (e.g., in a café).

To gain a deeper understanding of users' placement strategies and capabilities in retrieving virtual items we conducted two studies, which we present in the remainder of this chapter.

The Unadorned Desk 2D in the Design Space

Considering the classification for peripheral interaction, the Unadorned Desk 2D is designed to be operated while working on a computer (see Figure 8.2). Interaction is explicit through manual interaction (hovering and touching the desk) left and right of the keyboard, thus close by. In a study we showed that ten items in off screen space can be handled pretty well. Using both interaction spaces (left and right) in parallel increases the number to 20. Thus granularity is high. As the Unadorned Desk is not explicitly designed for a designated task, privacy may differ depending on the items that the user places in off-screen space. Touching and hovering includes inherent haptic feedback. Moreover our system offers additional visual feedback. Depending on the use case the Unadorned Desk is deployed for, functional feedback could be part of the system, but it was not applied in our study.

Concerning the task-based perspective, the Unadorned Desk could cover all characteristics, depending on the items that are stored in off-screen space and their dedicated task.

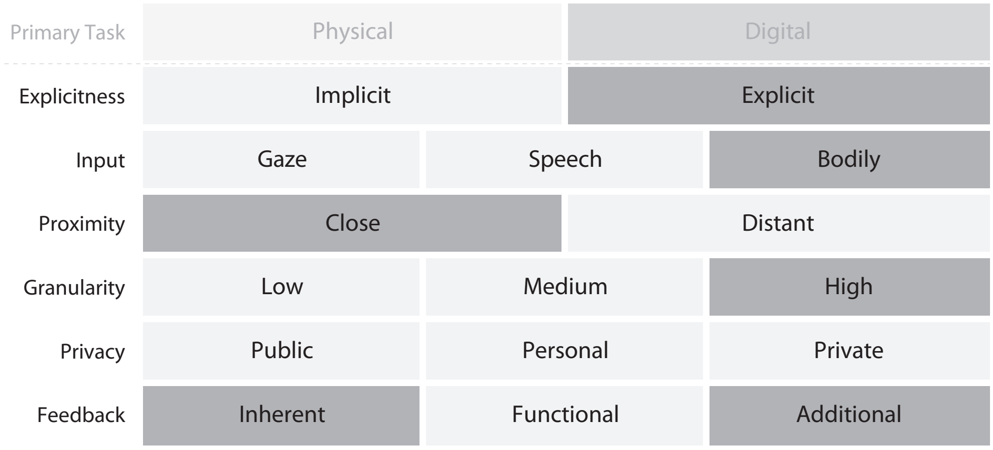

Figure 8.2: The Unadorned Desk 2D located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by the Unadorned Desk 2D.

8.1.1 Background: (Interactive) Desks and Spatial Interfaces

The Unadorned Desk is inspired by interaction with physical artifacts as well as interactive desks. Moreover we are interested to find out to which extent interaction based on spatial memory can be carried out without visual feedback. Thus we review several projects, which reduce or completely omit feedback.

(Interactive) Desks

Many researchers investigate work on desks, especially interactive tabletops. Although we do not rely on a tabletop device and do not offer visual cues on the desk itself, these works inspire the interaction on our interactive surface.

Organizing the Desk: On our physical desk we easily navigate for content and tools that are stored there. Either the physical arrangement offers us context information about the status or importance of a document [38] or associate tools are arranged to be available, thus nearby or at well-known locations (e.g., desk drawers) for easy retrieval [87]. According to Malone [160], documents are usually organized in either files (systematical organization, e.g., alphabetically) or piles (no deliberate organization, relying on spatial organization).
Several systems try to mimic our behavior on traditional desks. *Data Mountain* [207] supports the organization of bookmarks through a virtual table and proofed to be faster than bookmark organization in Internet Explorer 4. *BumpTop* [2] offers the arrangement of documents in a virtual 3D space. In general, customization features in graphical user interfaces let people spatially arrange tools on their desktop [87].

Augmented and Interactive Desks: Digital desks all aim at offering an enlarged interaction space beyond the constraints of a traditional computer display. Early work, such as the *Digital Desk* [252], aims at partially digitalizing the desk through projection. Additionally video cameras track fingers or pens for interaction. Moreover the Digital Desk can capture content on paper to interact with physical as well as analog data. *Augmented Surfaces* [204] extend the laptop's screen on a table or wall. Content from the laptop can thus be dragged onto the table and is visible there. *Bonfire* [143] also relies on a projection next to the laptop but offers interaction with the content on the desk through camera tracking. Most recent examples however rely on displays – most of the time horizontally oriented – and touch interaction (e.g., *Magic Desk* [31]). Further projects blend horizontal and vertical displays through a curve (e.g., *Curve* [259] and *BendDesk* [251]). Studies on such interactive desks show that the region next to mouse and keyboard is suitable for coarse interaction [31]. However, extending interaction space beyond display borders is not only investigated for desk-based scenarios but also in the mobile context (e.g., [72, 98, 122]).

Interfaces without Additional Feedback

Interfaces based on spatial memory seldom offer dedicated feedback. For example *Imaginary Interfaces* [93] only rely on the user's hand forming an L as reference frame (cf., Chapter 2.2.2). Others rely on an imaginary circle around users. Using *Spin & Swing* [7] one navigates by turning oneself. In contrast *Virtual Shelves* [154] is designed to store function in the hemisphere in front of the user. Other concepts rely on body location to hold functions (e.g., *Body-Centric Interaction* [51], *Gesture Pad* [203] and *BodySpace* [224]). *Point upon Body* [155] uses (up to six) regions on the forearm to store commands. While we not rely on body spaces, we will – similar to the here presented work – also make use of proprioception (cf., Chapter 2.2.1) and spatial memory (cf., Chapter 2.2.2) to access digital content.

8.1.2 Designing and Building the Unadorned Desk 2D

The Unadorned Desk is designed to store items, for instance commands, applications and tools, in off-screen space on the physical desk left or right of the keyboard and mouse. By touching the desk items are placed or retrieved again. To support this task we also investigate different feedback types.

Feedback

Overall we offer three different feedback types during the study: *no feedback* (none), *single item feedback* (single) and *full area feedback* (full). Single item feedback shows only the item closest to the hand. Additionally opacity depicts the distance to the item, thus the more opaque the item becomes, the closer the hand is to the item. Figure 8.3 displays single item feedback for the first study (a) as well as the second study (b). Full area feedback depicts the full interaction area and all items that are stored there according to their spatial arrangement. Again, opacity indicates the location of the hand. Thus, the item below the hand is the least opaque. Again Figure 8.3 shows full area feedback for both, the first study (c) as well as

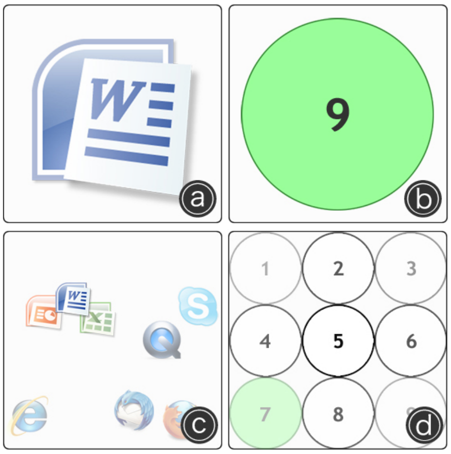

Figure 8.3: *Single Item Feedback*, (a) 1st and (b) 2nd study, showing the item closest to the participant's hand. *Full Area Feedback*, (c) 1st and (d) 2nd study, showing all items and their spatial layout. Opacity encodes the distance to items.

Figure 8.4: Setup of the Unadorned Desk 2D with the interaction area on the left of the keyboard observed by a Kinect depth camera, which is mounted facing upside down.

the second study (d). The feedback is shown on the computer's display in a 400 × 400 px window located close to the interaction area (thus on the left or right bottom corner of the screen). The feedback window is only shown when a hand is detected in the interaction area.

Implementation

To track the interaction we used a Microsoft Kinect depth camera, which was mounted on a tripod while facing upside down to observe a sub region on the physical desk (see Figure 8.4). The region covered on the desk is 40 × 36 cm (33.5 cm on top edge because of slight camera distortion) and located next to the keyboard and mouse on either the left or right side and aligned with the desk edges. The prototype runs on an Intel i7 3.4 GHz to offer fast processing, thus 640 × 480 px frames at 30 frames per second.

The camera offers depth images, which encode each pixel's distance to the camera in millimeters. When starting the system, a series of depth images are taken and averaged (to reduce noise) and taken as ground truth. While the Unadorned Desk 2D is running, the difference between each current image and the ground truth is calculated. The result is an image containing all new points (e.g., a hand) and the distance of these new points to the desk. We identify the point that is closest to the most distant corner of the interaction area, which usually is the tip of the middle finger. This point is later considered as touch point. Additionally, depth encodes the status of the hand: *touching* (depth $<$ threshold), *hovering* (depth $\geq$ threshold) or *absent* (no hand detected). While hovering in the interaction area, the feedback window is shown during the respective feedback conditions. Upon touching the desk, the associated command is triggered.

8.1.3 Evaluating Off-Screen Interaction in the Lab

We conducted two user studies based on the Unadorned Desk 2D. The first investigates how users spatially place items in off-screen space (and later retrieve them), while the second targets accuracy during retrieval.

Conditions for Both Experiments

Although we had varying tasks, two conditions were the same in both studies.

Handedness: We explored interaction with the *dominant* as well as the *non-dominant* hand. The interaction area was always located closest to the interacting hand, thus either located on the left or the right of mouse and keyboard.

Feedback: Based on the previously designed feedback conditions (see Figure 8.3) we compared *single item feedback*, *full area feedback* and *no feedback* at all.

Thus we carried out a within-subjects factorial design for both experiments: *2 Handedness (Dominant, Non-Dominant)* $\times$ *3 Feedback (None, Single, Full)*. Feedback was counterbalanced to minimize learning effects. Handedness however was alternated between participants to not always change the setup. Hence, the first participant carried out the task with all three feedback types with the dominant hand and afterwards with the non-dominant hand. The next participant then started with the non-dominant hand etc. All participants were seated centrally in front of the display, keyboard and mouse. Thus, the chair, display and keyboard were moved to sit comfortably in reach of the interaction area, which was aligned with the desk's edges. The tracked region on the desk was empty during the study.

Participants

We recruited 24 participants (12 per study; first study: 6 female; second study: 4 female). They ranged in age from 19 to 30 (average age 24). Every person only participated in one of the two experiments, thus minimizing learning effects. Our participants varied in handedness (first study: nine right-handed; second study: all right-handed). One session lasted up to 1.5h.

8.1.4 Study 1: Placing and Retrieving Content

With the first study we assessed two questions: (1) how do people arrange a given number of items in off-screen space and (2) how big is the offset when retrieving items. Thus, how big should an item be to assure a reasonable small error rate during retrieval.

To explore these two questions we added a third condition *Sets*, which consisted of 2, 4, 6 or 8 items to be placed and retrieved. We chose to use well known application icons, which all our participants were familiar with and had (also semantic) meaning to them. The application items were Word, Excel, Power Point, Firefox, Thunderbird, Skype, QuickTime, and Internet Explorer.

Task and Procedure

Each *Handedness* × *Feedback* × *Set* combination contained placement and retrieval.

Placement: Participants were instructed to place items at their own liking but with a minimal distance of 50 px (47.6 mm) to avoid overlapping of items. All items that should be placed during one trial were shown to the participants in the beginning. This knowledge could be used to group items and deliberately place them. To place an item in off-screen space, participants had to press the space bar to indicate the beginning of the placement. Afterwards they entered the interaction area with the respective hand. While hovering in the interaction area, feedback (if currently applicable) was given showing already placed items. When touching the desk, the item was placed. Participants repeated this until all items of one set have been placed.

Retrieval: Again participants were informed about the item that they should retrieve on the computer's screen. The items were randomized and only one item at a time was shown. Again they started each trial by pressing the space bar to indicate the start. A timer started, and participants could enter the interaction area, thus invoking the feedback window depending on the current feedback condition. Touching the desk now indicated retrieval of the item closest to the touched location. In case the closest item was not the correct item, we did not inform the participants and they carried on with the next item, but we recorded the error.

Sets were presented in ascending order (2, 4, 6 and finally 8) for each *Handedness* × *Feedback* combination to increase difficulty. Each item was retrieved four times, thus every participant (distributed over all conditions) placed 120 items and carried out 480 retrievals.

During placement we recorded the *x,y-coordinate* of every item (as center of the placed item). For retrieval we measured the *time* from beginning of the trial (indicated by pressing the space bar) until touching the desk and the *offset* to the correct item. Additionally we recorded *errors* (if and how many items were closer to the touch point than the intended item). Moreover the experimenter manually recorded (by key presses, which were counted by a small application) *gazes* into the interaction area, the feedback area or both.

After each *Handedness* × *Feedback* combination, participants filled out a questionnaire. After completing all trials they were handed a final questionnaire comparing all combinations.

Results

We used repeated measures within-subjects analyses of variances (ANOVA) to analyze our data. For pair-wise post hoc tests we used Bonferroni-corrected confidence intervals to retain comparisons against $\alpha = 0.05$. When the assumption of sphericity was violated, we used

Greenhouse-Geisser to correct the degrees of freedom. All unstated p-values are $p > 0.05$. (This also refers to the second study in Chapter 8.1.5.)

When performing a $2 \times 3 \times 4$ (*Handedness* × *Feedback* × *Sets*) withing-subjects ANOVA, we did not find any significant effect or interactions for *Handedness*. Thus for further analyses we aggregated over *Handedness*. For all heat maps we mirrored interaction on the right side of the keyboard to the coordination system of the left interaction area.

Placement Strategies: When analyzing the heat maps with all placements (see Figure 8.5) one can observe that participants arranged items based on an imaginary grid. We were able to distinguish three semantic patterns during placement. One participant placed items in single row (similar to the Mac OS X dock) and (during feedback conditions) hovered over the line to find the correct item. Others hierarchically grouped items and put related items (e.g., all browsers) closer together. During retrieval they first roughly located the area with all related items and only then precisely located the distinct item. Additionally, some based their placement on personal usage (outside of the study). Thus applications they used less often were placed further away than applications they regularly used. This already hints at the fact, that reaching further away was considered to be more cumbersome or physically demanding. However they still made use of the whole area to more comfortable access individual items as they are placed further apart.
We also analyzed the distances (closest, average and highest) between all items. Overall the distance between items ranged from 207.4 to 231.6 mm ($m = 219.2$ mm, $sd = 9.7$ mm) for all conditions. We further investigated the influence of *Feedback* and *Sets* on the distance between items during placement, by calculating an individual ANOVA for each distance. For **closest distance** we found a significant main effect for *Set* ($F_{1.953,21.487} = 184.76$, $p < 0.001$). Post hoc tests showed that smallest distances increase when the *Set* size decreases (all pairs except *6* and *8*, differ ($p = 0.011$) independent of *Feedback*). This again indicates that people made use of the space and placed items further apart if they could (e.g., because they only had to place few items). For the **highest distance** we found a significant effect for both, *Feedback* ($F_{2,22} = 15.49$, $p < 0.001$) and *Sets* ($F_{3,33} = 128.75$, $p < 0.001$). Highest distance actually decreases for smaller *Sets* (significant for all but *6* and

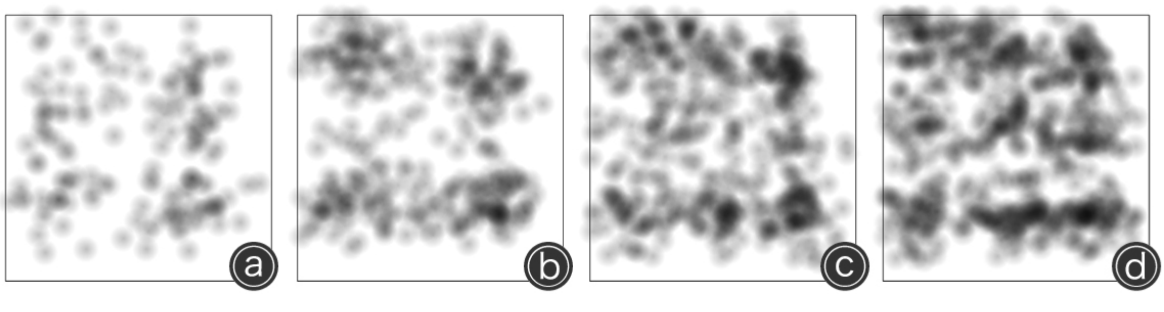

Figure 8.5: Heatmaps for placements in the left interaction area. All placements from the right interaction area were mirrored and incorporated into this figure. (a) 2 items, (b) 4 items, (c) 6 items, and (d) 8 items.

8; $p < 0.001$). We here also found that *None* lead to higher distances ($p < 0.05$). Thus with feedback present, participants felt more secure to put items closer together. Only for a *Set* of *4* items did we not find any significant effect. We believe this is because participants there relied on the four corners of the interaction area.

Retrieval Time: We measured retrieval time from hitting the space bar till touching the desk and thus selecting an item. For statistical analysis we only counted correct retrievals (although there was no significant difference between retrievals with and without errors). When performing a 3×4 (*Feedback* $\times$ *Set*) within subjects ANOVA, we found a significant main effect for *Feedback* ($F_{2,20} = 31.098$, $p < 0.001$) and for *Set* ($F_{1.609,17.698} = 15.583$, $p = 0.011$). Figure 8.6a indicates higher retrieval times for larger *Sets*. Additionally, *Feedback* also influenced retrieval time. Performing separate ANOVAs for each *Set* shows that *None* is always faster (all $p < 0.001$). Moreover, conditions with visual feedback are more strongly affected by increasing *Sets*. Overall, *None* ($m = 1.40$s, $sd = 0.36$s) was fastest followed by *Full* ($m = 2.47$s, $sd = 0.88$s) and *Single* ($m = 2.68$s, $sd = 1.06$s).

Retrieval Offset: We calculated the offset (distance between the touch point and the actual items location) for each successful retrieval (thus omitting trials where participants probably forgot about the location). For a 3×4 (*Feedback* $\times$ *Set*) within subjects ANOVA we found a significant effect for *Feedback* ($F_{2,22} = 4.201$, $p = 0.028$). Independent of *Sets*, offset was smallest for *Full* ($m = 36.6$mm, $sd = 12.6$mm) followed by *Single* ($m = 41.1$mm, $sd = 18.1$mm) and *None* ($m = 48.9$mm, $sd = 24.6$mm). Figure 8.6b shows, to have 95% of successful retrievals independent of *Feedback* and *Set*, one needs a radius of at least 85mm.

Errors: We analyzed the impact of *Feedback* on wrong retrievals (other items were closer than the intended one). To do so we normalized the data, thus dividing the number of incorrect closer items by the maximum number of possible wrong items (i.e., 1 for a set of 2, 3 for a set of 4, etc.). By performing a 3×4 (*Feedback* $\times$ *Set*) within subjects ANOVA we found

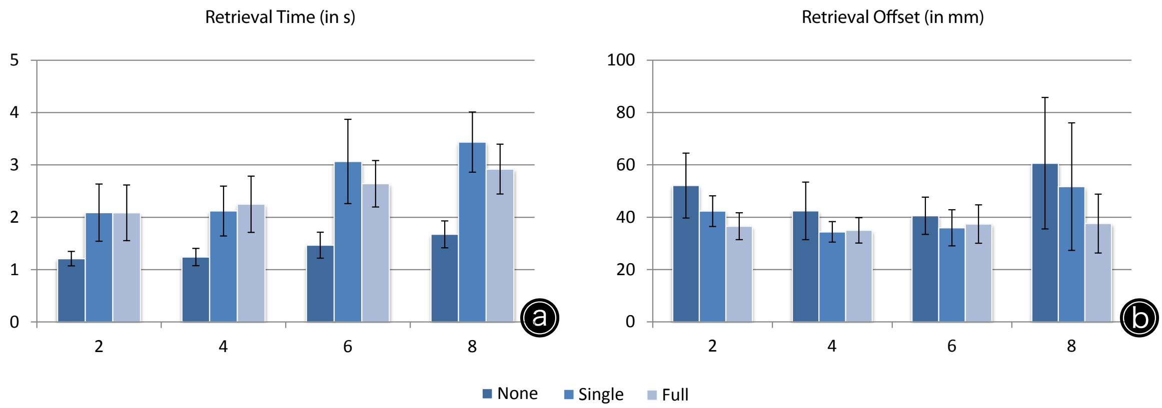

Figure 8.6: Quantitative Results for Study 1: (a) retrieval time (in seconds) and (b) retrieval offset (in millimeters). Error bars indicate 95% confidence intervals.

a main effect for *Feedback* ($F_{1.22,13.419} = 4.914$, $p = 0.039$). Post hoc test showed that only for *Sets* with *6* items *None* causes more errors ($p = 0.04$). With the current set up chances for an erroneous selection are 20% (*sd* = 12%) for *None* and 15% (*sd* = 8%) for *Single* and *Full*. However, this can be lowered by increasing the minimum distance for placement.

Gazes: At the beginning of the study we instructed the participants to minimize looking at the interaction area but instead imagine an on-screen primary task, which captures their attention. In contrast we did not give them any instructions concerning the feedback window. Thus they were completely free to use it or ignore it. All gazes are reported here across placement and retrieval. For gazes in the interaction area we performed a 3 × 4 (*Feedback* × *Set*) within subjects ANOVA and found a significant effect for *Feedback* ($F_{1.1226,12.383} = 7.948$, $p = 0.012$), *Set* ($F_{3,33} = 14.498$, $p < 0.001$) and *Feedback* × *Set* ($F_{2.15,23.645} = 8.618$, $p < 0.001$). Post hoc tests showed that participants gazed more at the interaction area in the *None* condition compared to *Single* for *6* items ($p = 0.027$) and more compared to *Single* and *Full* for *8* items ($p = 0.016$). Overall we recorded most gazes to the interaction area in the *None* condition (24% of all trial), followed by *Single* (11%) and *Full* (12%).
Gazes in the feedback area were of course analyzed without the *None* condition as no feedback area was available there. We performed a 2 × 4 (*Feedback* × *Set*) within subjects ANOVA and found a significant effect for *Set* ($F_{2.121,23.334} = 7.274$, $p = 0.002$). Post hoc tests revealed that gazes to the feedback area increased with larger sets, thus *2*/*4* differs from *6* ($p = 0.044$), and *2* from *8* ($p = 0.021$). For gazes at the feedback area, participants gazed there 72% of all trials during *Full* feedback and 66% during *Single* feedback. Thus, participants "left" their fictive primary task more often when feedback was present, however, as they not always gazed at the feedback, they also felt able to carry out the task without checking the feedback for more than a quarter of all trials.

8.1.5 Study 2: Targeting Content

We conducted the second study based on findings from the first study but aimed at reducing effects due to the memorization of items, as we cannot mimic that properly in a lab based study. We observed in the first study, that participants tended to arrange items along an imaginary grid. Hence we used prearranged grids of items for our second study.

We introduced the new variable *ItemSize* consisting of three levels: *Small* (diameter: 10 cm), *Medium* (13.3 cm) and *Large* (20 cm) items. With these items we filled complete grids thus having three different grids: 16 (4 × 4) *Small*, 9 (3 × 3) *Medium* and 4 (2 × 2) *Large* items.

Task and Procedure

The task was similar to the first study, but only consisted of the retrieval phase. Participants were instructed on-screen, which item to retrieve (the grid was graphically displayed to them and the item that should be retrieved was highlighted). Again participants started a trial by pressing the space bar and thus starting the timer. They entered the interaction area with their hand, and in case of a feedback condition, feedback was shown on the display. When touching the desk the timer was stopped. In case of an error, participants this time were notified and could try again. However, after the third attempt we moved on to the next item to avoid frustration. Overall, every item was retrieved three times and items and grids were randomized during the retrieval phase. Thus, every participant retrieved 522 items during the experiment, but we excluded the first block as training block from the later analysis.

For evaluation we logged *task time* (from hitting the space bar till touching the table), the *offset* (as Euclidean distance between the touch point and the item's center) and the *number of errors* (with a maximum of three errors per item). We again manually tracked *gazes* to the feedback and interaction area. Participants filled out a questionnaire after each *Handedness* $\times$ *Feedback* combination and a closing questionnaire at the end of the study.

Results

Analog to the first study we did not find any significant results for *Handedness* when we conducted a $2 \times 3 \times 3$ (*Handedness* $\times$ *Feedback* $\times$ *ItemSize*) within subjects ANOVA. Thus we again aggregated over *Handedness* for all further analyses. Additionally, for retrieval time and offset we excluded all unsuccessful attempts, as participants only had three attempts and not always successfully retrieved each item. Hence we excluded 6.5% of all trials.

Retrieval Time: To asses retrieval times we calculated a 3×3 (*Feedback* $\times$ *ItemSize*) within subjects ANOVA and found a significant effect for *ItemSize* ($F_{1.272,13.997} = 15.269$, $p < 0.001$), *Feedback* ($F_{2,22} = 19.037$, $p < 0.001$) and *ItemSize* $\times$ *Feedback* ($F_{4,44} = 5.414$, $p < 0.001$). Post hoc tests revealed that retrieval time is differing for all *ItemSizes* when comparing *Single* and *Full* to *None* (all $p < 0.001$). For both, *Single* and *Full*, retrieval time is significantly longer for *Small* items compared to *Medium* and *Large* (all $p < 0.001$). On

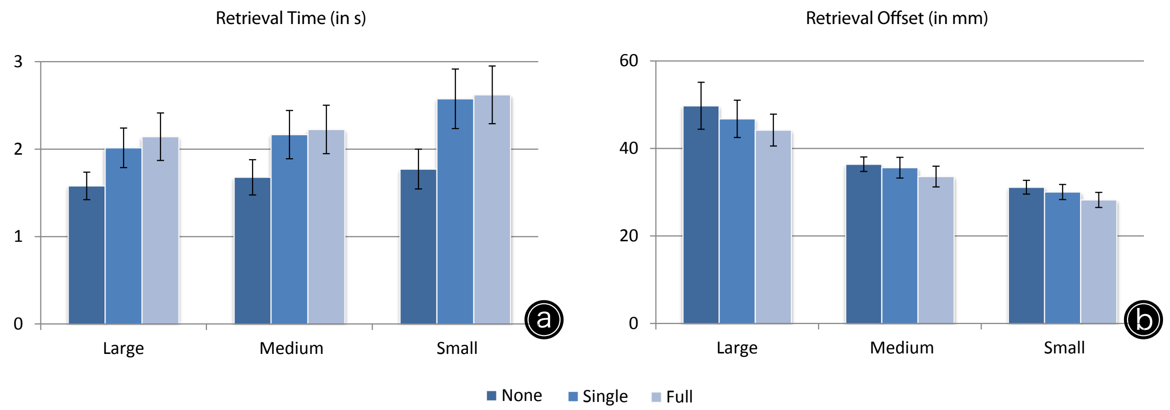

Figure 8.7: Quantitative Results for Study 2: (a) retrieval time (in seconds) and (b) retrieval offset (in millimeters). Error bars indicate 95% confidence intervals.

average, retrieval time was fastest for *None* (m = 1.68s, sd = 0.35s) followed by *Single* (m = 2.25s, sd = 0.50s) and *Full* (m = 2.33s, sd = 0.52s) (see Figure 8.7a).

Offset: To analyze the offset for each retrieval we had to normalize the data because different *ItemSizes* have different possible maximal offsets. Thus we divided the measured offset by the maximum possible offset (i.e., the item's radius). Afterwards we conducted a 3 × 3 (*Feedback* × *ItemSize*) within subjects ANOVA and found a significant effect for *ItemSize* ($F_{2,22} = 39.318$, $p < 0.001$) and *Feedback* ($F_{2,22} = 4.918$, $p = 0.016$). Post hoc tests showed that for *Large* items, participants were relatively closer to the center ($p = 0.007$), however, as the items were larger, they still were physically further away. Thus, relatively we measured the smallest offset for *Large* items (m = 46.9% of the item's width), followed by *Medium* (m = 52.1%), and *Small* (m = 59.5%). However, comparing with the non-normalized offsets (see Figure 8.7b) we found the least offset for *Small* items (m = 29.7mm, sd = 3.0mm), followed by *Medium* (m = 34.6mm, sd = 3.8mm) and *Large* (m = 46.9mm, sd = 7.8mm) ones. However, the average offset we measured for *Large* items would still have been sufficient for *Small* items.

Errors: Again we normalized the data as depending on the *ItemSize* the number of items in the grid differed. Thus we divided the errors by the number of items in the grid for each trial. We then performed a 3 × 3 (*Feedback* × *ItemSize*) within subjects ANOVA and found a significant effect for *ItemSize* ($F_{2,22} = 88.909$, $p < 0.001$), *Feedback* ($F_{1.309,14.4} = 10.587$, $p = 0.002$) and *Feedback* × *ItemSize* ($F_{2.126,23.385} = 4.036$, $p = 0.028$). Post hoc tests revealed that *None* caused significant more errors than *Single* and *Full* for *Large* ($p = 0.018$) and *Small* items ($p = 0.008$). However, we did not find any effect for *Medium* items. Overall, we recorded the most errors for *None* (for all *ItemSizes*) (m = 41%, sd = 23%), followed by *Single* (m = 22%, sd = 16%) and *Full* (m = 18%, sd = 10%). Additionally, error ratio increased from *Large* (m = 6%, sd = 6%) to *Medium* (m = 18%, sd = 7%) and *Small* (m = 57%, sd = 12%) items (including all feedback conditions).

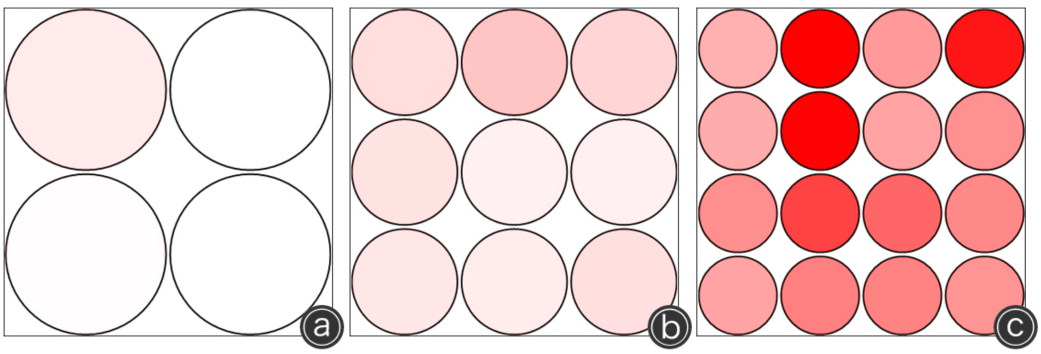

Figure 8.8: Heatmaps for errors in the left interaction area. All placements from the right interaction area were mirrored and incorporated into this figure: (a) large items; (b) medium items; (c) small items.

Figure 8.8 shows, which areas caused the most errors (all errors from the right interaction area are mirrored to the left). For *Large* items the corner furthest away is the most error prone. For *Small* items, most errors occur in the middle. We performed a second analysis, a 3 × 3 (*Feedback* × *ItemSize*) within subjects ANOVA, excluding the items furthest away (*Large*: top left, *Medium*:, three furthest away, *Small*: six furthers away). We found a significant effect for *ItemSize* ($F_{2,22} = 23.941$, $p < 0.001$) and *Feedback* ($F_{1.332,14.648} = 9.973$, $p = 0.003$). Post hoc tests further showed that *None* differed from *Single* and *Full* just for *Small* items ($p = 0.045$). However, even if not significantly, *None* is still the most error prone for all *ItemSizes* with the least errors for *Large* items with 3.7% errors per trial (sd = 2.7%) (*Single*: $m = 1.2\%$, $sd = 1.9\%$, *Full*: $m = 1.9\%$, $sd = 2.7\%$). *Medium* sized items lead again to most errors for *None* ($m = 4.5\%$, $sd = 3.8\%$) (*Single*: $m = 2.7\%$, $sd = 3.6\%$, *Full*: $m = 1.6\%$, $sd = 1.5\%$). Finally, *Small* items caused the most errors with *None* ($m = 8.6\%$, $sd = 3.6\%$), *Single* ($m = 4.9\%$, $sd = 3.2\%$) and *Full* ($m = 4.0\%$, $sd = 2.0\%$).

Gazes: Analog to the first study we again instructed participants to minimize looking at the interaction area during retrieval. To assess these gazes, we again performed a within subjects ANOVA for *Feedback* and found a significant effect ($F_{1.136,12.495} = 10.485$, $p = 0.004$). Thus participants gazed more at the interaction area for *None* than they did for *Single* and *Full* feedback ($p = 0.022$). Analyzing gazes towards the feedback area (again of course without the *None* condition), we found no significant difference for *Single* and *Full*. Overall, *None* caused the most gazes at the interaction area ($m = 22.7\%$ of all trials, $sd = 23.7\%$ followed by *Single* ($m = 4.7\%$, $sd = 7.2\%$) and Full ($m = 5.6\%$, $sd = 9.7\%$). During feedback conditions, our participants gazed at the feedback area a little more with *Full* ($m = 69.1\%$ of all trials, $sd = 22.7\%$) than with *Single* ($m = 65.0\%$, $sd = 21.3\%$).

8.1.6 Lessons Learned

The Unadorned Desk 2D is designed to investigate how people can use off-screen space next to mouse and keyboard on their desk to store virtual elements and retrieve them in a coarse and at best peripheral way.

Envisioned Applications

The described studies with the Unadorned Desk was independent of any real life task. However, we built a set of example applications[2] to demonstrate basic uses of off-screen space. The first application involves task-switching. When users bring their hand into the interaction area, the display shows all open windows (see Figure 8.9a). Users can then select the window of interest (i.e., the hand's location is mapped to the windows' locations). The second application illustrates tool selection. People change tools in Adobe's Photoshop without moving the mouse to the icon of that respective tool (see Figure 8.9b). The third application

[2] The video figure illustrates all three applications: http://youtu.be/ePQxR3EzJ_I (Last Accessed: 14.07.2013)

Figure 8.9: Example applications for the Unadorned Desk 2D: (a) switching between open windows; (b) selecting tools in Photoshop; and (c) changing the state in Skype.

(inspired by StaTube, cf., Chapter 6.1) involves state changes, where people change their Skype state by tapping on the respective location on the desk (see Figure 8.9c).

Summary and Limitations

The Unadorned Desk 2D consists of a physical desk, which is observed by a depth camera. In the interaction area (either left or right of mouse and keyboard) people can store and retrieve virtual items such as commands or applications. We conducted two studies with the Unadorned Desk 2D to explore how people make use of the available space for placing items and which constraints need to be considered to assure successful retrieval. In the first study we found that participants made use of spatial arrangements and mostly placed the items based on an imaginary grid. Both feedback conditions helped our participants to remember positions and thus decreasing offset during retrieval. However, retrieval time increased when feedback was available. The second study reinforced the results. We further found that small items (radius of 5 cm) were too small to be usable with a reasonable error rate. Moreover, items located further away from keyboard and mouse caused more errors, which is in line with findings from the Magic Desk [31], which also reported longer task completion times and problems for acquiring more distant targets.

However, this study is only lab based and thus rather artificial. Participants placed and retrieved items with no personal meaning to them. Additionally, the interaction style is envisioned to be executed in parallel to a primary task, which we also did not include in the study. Moreover, some technical difficulties are not resolved yet. The setup is too big for permanent real world deployment and interaction with the system cannot yet be distinguished from other movement around the desk (e.g., when reaching for a book). However, we aimed at a lower bound exploration to assess if this kind of interaction – relying on spatial memory with only minimal augmentation of the desk – is executable at all. We overall found that the system worked very reliably for a small number of items. While in a real life situation one can imagine that people want to store many different things, related work already shows that even a small number of commands can cover a large number of actions that are executed [87]. Thus, with advancements concerning tracking and further research to make interaction distinguishable from other movement at the desk (e.g., through distinct gestures, cf., Chapter 8.2), we believe that this kind of interaction can be successfully deployed. We again want to stress that this is a lower bound investigation, thus it is very likely that results are better in a real life setting because virtual items are meaningful linked to tasks and traditional desks offer much more landmarks than our study desk. Moreover, peripheral interaction – as established in previous chapters – needs time to become habituated to be easily carried out. This could also not be achieved in our lab based evaluation.

Generalizable Findings for Peripheral Interaction

We investigated how participants dealt with placement and retrieval based on spatial arrangements on the desk. From this we derived some general findings for peripheral interaction based on spatial memory.

Interaction based on Spatial Memory: During the placement phase in the first study we observed that participants – without instructions from us – started to make use of spatial arrangements. It thus seems to be the obvious choice when presented with such a task. When being asked about the task in general, they considered it fairly easy and enjoyed the interaction. Some people even compared touching the desk at certain locations to a game (cf., Whac-A-Mole).

Handedness: In both studies we could not find any significant difference between interaction with the dominant or non-dominant hand. Thus we conclude that this type of interaction actually is coarse and does not rely on fine grained movement and because of this is suitable to move into the periphery once having gotten used to it. This also implies that both interaction areas could be made available in parallel and people can choose on their own, which area currently is more suitable for them and their task (e.g., depending on the hands occupation by for instance the mouse or keyboard).

Scalability: Scalability is affected by two parameters: the *number* of items and the *size* of items. These two parameters also influence each other, as depending on the size of an item only a limited number of items fit into the space at the desk around mouse and keyboard and especially at arm's length. In the first study we observed that two and four items work very well, however, in the second study, we found that favorable arrangement (cf., next paragraph on location) can improve the number, thus results from the second study suggest that such a system still works well for up to *ten items*. Based on related work [87], this can already be enough for most actions. Concerning the item's size, our first experiment, which relied on placement by the participants, implied a 8.5 cm radius (thus 17 cm big items) to achieve 95% correct retrievals for any feedback type and number of items. Our second study showed that medium items (thus 13.3 cm big), arranged in a grid, also worked very well (although not 95% correct retrievals). We can conclude, that location and arrangement of items can positively influence retrieval in terms of offset and errors.

Location: As the paragraph on handedness already implies, there was no measurable influence when using the left or the right interaction area. However, within one interaction area we did find differences. Participants themselves always tried to space items and thereby used the whole interaction area. While leaving enough space between two items indeed is important (see Scalability), our analysis showed that not every location in our (rectangular) interaction area is equally well suited for this type of interaction. Participants themselves also stated that they prefer locations rather close by. Measured data also supports this, as we found in the second study that items above the diagonal (i.e., the items furthest away) are the most error prone (which is in line with findings from the Magic Desk [31]). When excluding these items we found that error ratio only increased for small items when not offering feedback. Thus, we believe that the location of an item (if reasonable sized) is more relevant for successful retrieval than feedback. Additionally landmarks are very important. Items at the borders were more easily retrieved. Taking the system from the lab to real life desks other physical items on the desk (e.g., the telephone) can also act as landmarks and therefore improve retrieval. Taking these findings into account, our rectangular shape might not be the most suitable, but locations for placement of items should be selected based on the individual desk configuration and especially consider landmarks on the desk at easy reach.

Visual Attention: We analyzed visual attention that was drawn to the interaction area as well as the feedback area. For most trials participants did not look at the interaction area. This indicates that the task itself – touching off-screen space on the desk at a distinct location – can be carried out with minimal visual attention. Especially when taking into account, that participants stated that sometimes they just looked there because there was nothing else to look at, as we did not give them a primary task during the study. Concerning feedback the result is inverse, thus, while not always using the feedback window it was used in most cases. Consequently, feedback did draw visual attention on it, probably more than necessary, especially for larger item sizes and smaller item numbers. However, we believe the number of gazes towards the feedback might also decrease when introducing a primary task.

Feedback: In both studies we observed that retrieval time increased when feedback was available. We found several reasons for that: (1) Participants stated that they started searching instead of thinking about the placement. Moreover (2) participants felt pressured to point more precisely when feedback was available, although that was most of the time not necessary. We cannot completely rule out that it was not the feedback in general but the distinct feedback design. However, this effect was apparent for both feedback conditions while on the other hand (at least for large and medium sized items) errors did not immensely increase without feedback. However, without any feedback, participants were lost if they forgot about an items location. Additionally, during the first study, they did not have any clue if they touched the right item. However, in a real life situation the items would be associated with a task or command, which most likely would offer some kind of feedback (e.g., functional feedback) about the outcome. As already stated in the paragraph on location, if other parameters are adjusted well, feedback might be omitted without any negative effects but potentially increased interaction speed and free visual attention.

8.2 Exploration: Unadorned Desk 3D

Following up on the Unadorned Desk 2D we extended the prototype to also track the third dimension and thus building the Unadorned Desk 3D[3] [157] (see Figure 8.10). This extension is motivation by two reasons: (1) Related work already told us that people usually arrange items on their desk in piles [160]. However, the Unadorned Desk 2D does not support this, although we can imagine various use cases (e.g., stacking different browser tabs or different brush sizes in a graphics editing program). (2) Moreover, one limitation of the Unadorned Desk 2D is, that every touch on the desk is recognized as input to the system. Consequently we are interested in gestures to explicitly place and retrieve items and thus distinguishing this interaction from regular movement around the desk.

We conducted a study to find out (1) how participants make use of the 3D interaction volume and (2) which selection gestures work best. Again we are relying on spatial memory (cf., Chapter 2.2.2) and proprioception (cf., Chapter 2.2.1). However, in contrast to the Unadorned Desk 2D we did not give any additional feedback, as we found for the Unadorned Desk 2D that it slows down participants and is not really necessary when only storing a small number of items in off-screen space. Moreover, similar to the Unadorned Desk 2D studies, we are aiming at a lower bounds exploration, thus investigating if and to which extent people can interact with this minimally augmented desk.

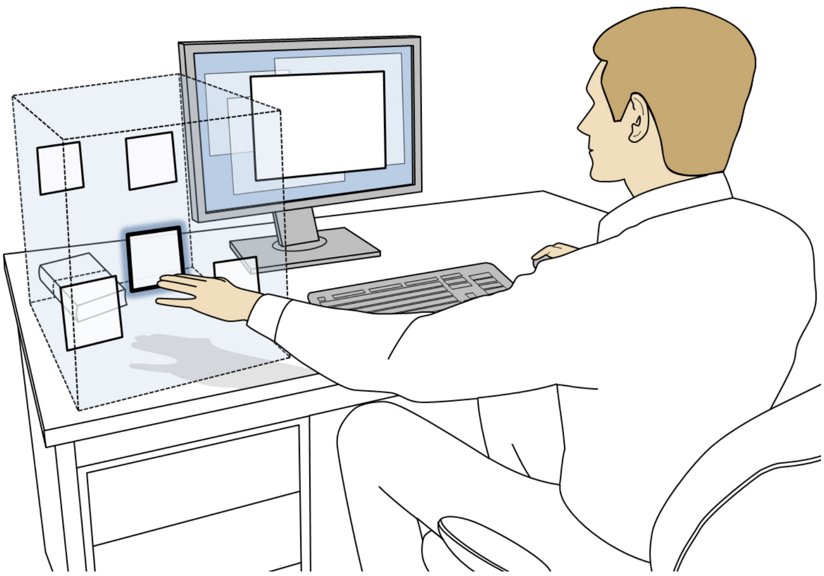

Figure 8.10: The Unadorned Desk 3D offers a storage space for virtual items (e.g., commands or applications) left (and/or right). Through a distinct selection gesture, items are placed and retrieved.

[3] The Unadorned Desk was extended into the 3rd Dimension by Xaver Loeffelholz von Colberg under the supervision of Doris Hausen and Sebastian Boring: Loeffelholz von Colberg, X. *The Unadorned Desk - Erweiterung in die dritte Dimension*, Bachelor thesis, University of Munich (LMU), Germany, 2013.

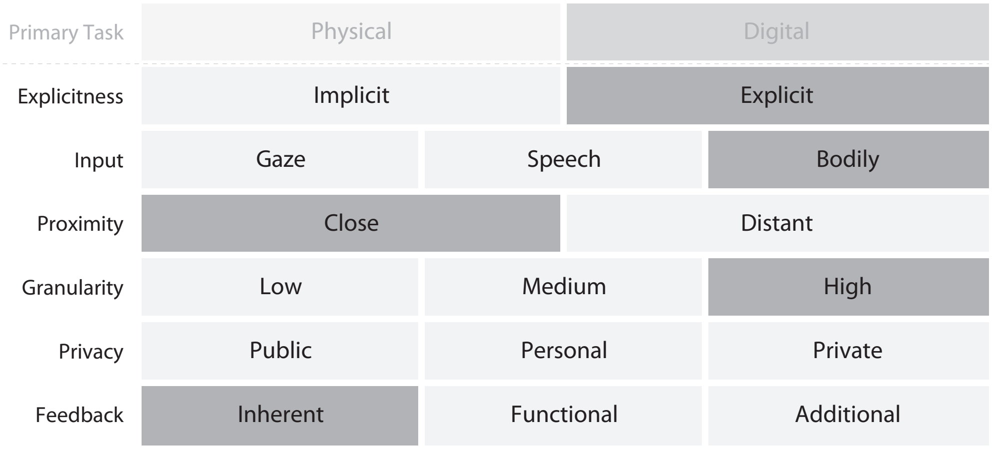

Figure 8.11: The Unadorned Desk 3D located in the classification for peripheral interaction. Dark grey depicts, which dimensions are covered by the Unadorned Desk 3D.

The Unadorned Desk 3D in the Design Space

The Unadorned Desk 3D, similar to the Unadorned Desk 2D, is also designed as complimentary task while working on a computer and interaction is carried out explicitly, but not through touch but through freehand gestures in the 3D interaction volume (see Figure 8.11). Interaction thus is also close by. Again a multitude of items can be stored, thus granularity is high, but privacy depends on the items users store there. Concerning feedback we now only rely on inherent feedback based on proprioception, but of course depending on a real life use case other types of feedback might be present (e.g., functional feedback).

Just like the Unadorned Desk 2D, the task-based perspective depends on the associated task and items. Again we evaluated the system in the lab without a dedicated task.

8.2.1 Background: Interaction in 3D

As the Unadorned Desk 3D is an extension to the previous system, of course related work discussed in Chapter 8.1.1 is still relevant for this project. However, we here now also explore interaction in the 3D dimension and not solely on the desk's surface.

To add interaction in the third dimension to interactive desks or displays, different locations are used. Marquart et al. [164] explore the space on and above a tabletop as continuous input space. *Interaction in the Air* [113] also makes use of the space above a tabletop with the goal to simulate 3D interaction based on real world physicality. In contrast both, *SpaceTop* [150] and *HoloDesk* [114] use the space behind a (vertical) display for 3D interaction, thus mimicking seeing through a display. Wang et al. [247] however use the space in front of a vertical display to track hands in six degrees of freedom to offer manipulation of digital content.

Our work also aims at 3D interaction above a desk, but in contrast to tabletops we rely on a traditional physical desk and only track the hands via a depth camera to just minimally augment the otherwise regular desk.

8.2.2 Extending the Unadorned Desk into the 3rd Dimension

The Unadorned Desk 3D is an extension to the previous prototype. For this exploration we added a second depth camera, to observe both interaction areas in parallel as we did not find any significant difference for the left and right interaction area in the first two studies. Moreover we added different gestures for placement and retrieval to the system, thus we are now able to distinguish between intentional interaction with the system and other movement on the desk, for instance grasping items stored on the desk such as pens or books.

However, we not only added functionality, we also removed the feedback from the system, as we found in the first study, feedback slowed participants down during retrieval. Of course there is need for feedback in case a user forgets about the location of an item in a real life scenario. However for our study, we were more interested in exploring the lower bounds constraints of such a setup and did not want to add a further variable concerning the feedback design, which is much more difficult for a 3D volume than our previous 2D interaction area, and might thus even have negative effects if designed inappropriately.

Gestures

We designed all gestures to be carried out eyes-free and with minimal cognitive load. With our evaluation we aim at exploring user acceptance and general suitability of them. Overall we address three categories of gestures, which are all depicted in Figure 8.12: *metaphorical gestures* based on the way people grasps objects in physical life, *spreading fingers*, which are abstract but easy performable gestures and *dwell time* as steady gesture, which does not require finger movement during selection.

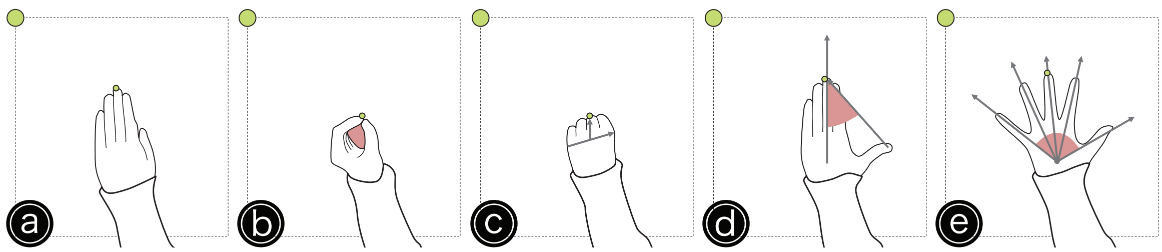

Figure 8.12: Selection gestures for placement and retrieval. From left to right: (a) *Dwell Time*, (b) *Pinch*, (c) *Fist*, (d) *Thumb* and (e) *Fingers*. Green dot in the top left corner denotes origin of coordination system. Small green dot at hand indicates tracked x,y coordinate.

Metaphorical Gestures: We included two gestures based on grasping physical objects. *Pinch* mimics grasping small or fragile items by joining thumb and index finger [258]. *Fist* in contrast mimics grasping bigger and heavier items. By forming a fist items are selected in off-screen space.

Spreading Fingers: We implemented two more abstract gestures based on spreading a different amount of fingers. *Thumb* triggers a selection by just spreading the thumb [243], while spreading *Fingers* expects all fingers to be spread to perform a selection.

Implementation

As already stated we extended the previous prototype and added a second depth camera (Microsoft Kinect), which is also mounted on a tripod facing upside down so both interaction volumes are observed in parallel (both: $44 \times 44 \times 44$ cm or $400 \times 400 \times 400$ px in the camera's coordinate space respectively) (see Figure 8.13). The Unadorned Desk 3D was implemented on an Intel i7 3.4 GHz computer with 8 GB main memory, which allows fast processing (i.e., 640×480 px frames from each camera at 30 frames per second).

Additionally we implemented the gesture tracking. We did not implement gestures to work in parallel, thus only one gesture at a time could be used to perform a selection. Figure 8.14 shows the gestures and their corresponding depth image.

Dwell Time: We implemented dwell time based on a threshold. If the hand moves below a given threshold (4 cm) a timer starts. If the timer (one second/30 frames) elapses and the hand did not move more than the threshold a selection is triggered.

Figure 8.13: Study setup for the Unadorned Desk 3D with two Microsoft Kinect cameras. The interaction volume is marked on the desk to give participants some landmarks on the otherwise empty desk. Vertically, the height of the monitor was indicating the limits of the interaction volume.

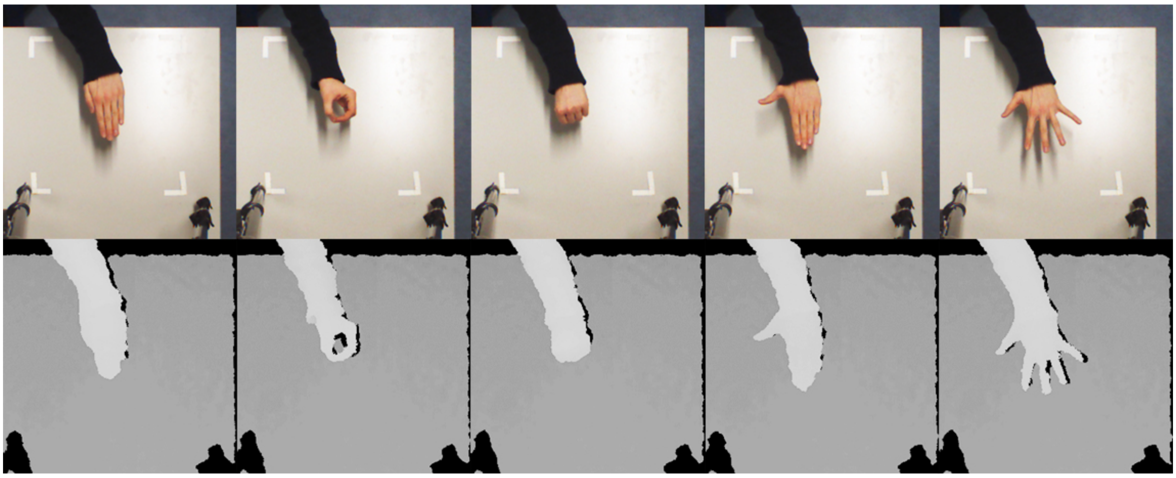

Figure 8.14: The five selection gestures (from left to right: *Dwell Time*, *Pinch*, *Fist*, *Thumb* and *Fingers*) and their corresponding depths image (contrast enhanced).

Fist: We calculate two vectors, vector u between the left-most and the right-most pixel of the hand and vector v between the mid-point of u and the topmost pixel of the hand. When dividing u and v we trigger a selection if the result is more than two (thus, u is much longer than v).

Pinch: We implemented the pinch gestures based on Wilson's [258] description. Thus we perform connected components labeling on the difference image. If we find only one component (i.e., the hand) nothing happens. Once we find a second component (i.e., the circle formed by thumb and index finger) a selection is triggered.

Thumb: To track the thumb gesture we calculate the vector between the right-most pixel (i.e., thumbs tip) and the topmost pixel of the hand (i.e., the middle finger). Afterwards we calculate the angle between this vector and the direction of the hand. If the angle is bigger than the threshold (40 degrees) a selection is triggered.

Fingers: To implement the tracking of spread fingers we perform a k-curvature algorithm to find extreme curves and thus the fingertips. If we find all five fingertips a selection is triggered.

All thresholds have been determined through experimentation.

8.2.3 Procedure of the Lab Evaluation

We target two questions with our exploration. (1) How do people make use of the 3D off-screen space and (2), which selection gestures are suited best for placement and retrieval?

Task

The task our participants had to carry out consisted again of the two phases – placement and retrieval. We included retrieval to motivate our participants to place their items in a reasonable manner. However, as retrieval in the lab only relies on short-term memory, we did not analyze retrieval time but looked at the offset for gestures and participants' preference.

Placement: During placement, participants were aware of all items that they had to place through on-screen instructions, as we expect that in a real life task people also know, which items they want to place and according to that pick a reasonable arrangement. To start placement participants had to press the space bar and afterwards could enter the interaction volume, to locate their preferred location (both, the left and right interaction volume could be used) and carry out the current gesture to place the item there.

Retrieval: Once all items were placed, participants were asked to retrieve them again. In randomized order one item after another was shown on-screen and retrieved. Again participants pressed the space bar to start retrieval, located the item in off-screen space and performed the current selection gesture. The item closest to the hand's position was considered as selected item. We always selected the closest item to not add another variable (i.e., item size) to the study and offer coarse interaction. In case of an error (thus the closest item was not the intended item) participants had to retry. However, after three attempts we moved on to the next item to avoid frustration.

After one trial, consisting of placement and retrieval with one of the five gestures, participants filled out a device assessment questionnaire and in the end, after having used all gestures, they were handed a comparative questionnaire.

For placement we recorded the *x,y,z-coordinates* of the performed gesture as location for the item. For retrieval we again recorded the *x,y,z-coordinates* and calculated the *offset* to the intended item. Additionally we counted the *number of errors*.

Participants

We conducted our study with 20 participants (four female). They ranged in age from 17 to 55 (average age was 27). One of our participants was left-handed.

Experimental Design and Procedure

We had two independent variables. *Gestures* consisting of *Dwell Time*, *Pinch*, *Fist*, *Thumb* and *Fingers* and additionally *Sets* consisting of *4*, *7* and *10* items. Thus we performed a *5 Gestures* $\times$ *3 Sets* within-subjects design. *Gestures* were counterbalanced to minimize effects of fatigue and learning. *Set* however were presented in ascending order mimicking real life tasks, where participants start with few items and add more and more to the off-screen space.

8.2.4 Results of the Evaluation

When conducting the experiment we were especially interested how our participants make use of the interaction volume, thus we were interested in the spatial organization of items and the effect of gestures on placement and retrieval.

Placement of Items

When analyzing the placement of items we carried out a two-step analysis: first we looked at the distribution between the left and the right interaction volume and afterwards we looked at fine-grained positioning within one interaction volume.

Choosing Sides: Participants were free to place items either in the left (see Figure 8.15a) or in the right interaction volume (see Figure 8.15b). During the study, both interaction volumes were used nearly equally (1006 items were positioned left, 1094 (52.1%) on the right). However, for smaller number of items we found a slight preference for the right interaction area. When asked to place four items (overall 400 placements), 228 (57%) items were located in the right interaction volume. For seven items (700 placements), 371 (53%) items were placed on the right, however for ten items (1000 placements), 495 (49.5%) items were placed in the right volume. Generally we can report that participants do make use of space that is available and thus used both volumes.

Fine-Grained Positioning: We found that fine-grained positioning is independent of the side, too. Overall two observations are rather obvious when looking at placements: (1) Most items have been placed in the lower part of the volume close to the desk (75% below 15 cm). (2) The rest is stored further away with a tendency towards the middle of the interaction volume. To confirm our observation we performed a hierarchical cluster analysis based on squared Euclidean distances with Ward's linking method to form clusters. We inspected the dendrograms and found that a five-cluster solution matches the data best. As we did not find any difference between the left and right volume concerning the number and location of clusters we merged them (mirroring the right interaction volume to the left) for

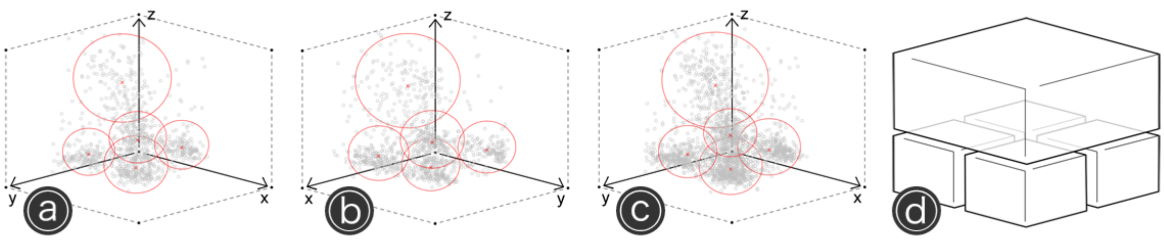

Figure 8.15: Cluster analysis for all placements (red circles indicate clusters): (a) all placements in the left interaction volume; (b) all placements in the right interaction volume; (c) all placements mirrored to the left interaction volume; and (d) schematic view of clusters.

further analysis (see Figure 8.15c). Overall 441 (21%) items were placed in the front right corner (corner closest to the participants), 313 (15%) items in the back right, 405 (19%) items in the back left and 440 (21%) items in the front left corner. 521 (25%) items were placed in the top cluster. We did not find any influence of gestures on placement.

Placement Strategies: Cluster analysis already implied that participants arranged their items based on imaginary grids (see Figure 8.15d). From all placement strategies we derived four distinct patterns, two of them in 3D and one only making use of 2D: *Pyramid* was used by five participants. They used the four corners and typically placed one item on top. Six participants built *Stacks*, by starting at the bottom (again typically in the corners) and then placed further items on top of other items. One participant only built one stack per interaction volume. Another strategy is *Top & Bottom* were participants used two planes differing in heights. This pattern was applied by four participants. Finally, participants, who applied *Plane* only used one plane for the arrangement of items, thus they ignored the third dimension. Most of this planes were located in the lower part of the interaction volume, however some were also located higher. This pattern was applied by seven participants.

Retrieval Offset

Retrieval was carried out directly after placement. We calculated the distance between the hand and the location of the expected item as retrieval offset. As only short term memory is tested in our study, we excluded all unsuccessful retrievals (17%), which mainly were caused by participants who forgot about the item's location. This number could be reduced by introducing feedback for a deployed system.

Influence of Gestures: In contrast to placement, we found that retrieval was influenced by the different gestures (see Figure 8.16a). *Fist* and *Fingers* caused the highest offsets followed by *Pinch*. We believe that this effect is based on the difference between the sensed and

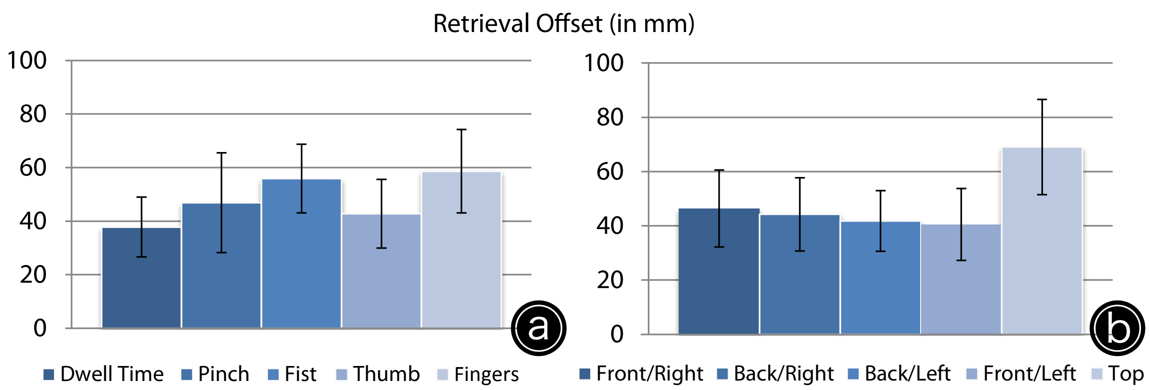

Figure 8.16: Retrieval offset in millimeters for (a) gestures and for (b) clusters. Error bars indicate 95% confidence intervals.

the perceived location. These three gestures all require movement of the hand respectively several fingers. For example for *Fist* participants hover in the interaction space with their flat hand, but when performing the selection gesture and thus forming a fist the knuckles are the tracked location. However, for all gestures, 95% of all successful retrievals were achieved with a maximum offset of 80 mm. For certain gestures, for instance *Dwell Time*, the maximum offset for 95% of all correct selections is reduced to 50 mm.

Influence of Clusters: As previously stated, participants used all clusters, however we observed an influence of cluster on the retrieval offset. As Figure 8.16b shows, the top cluster causes much bigger offsets than the bottom clusters. This is true for all gestures, thus the already worse performing gestures (*Fist*, *Fingers* and to some extent *Pinch*) performed worse for the top cluster compared to the bottom clusters, but also *Dwell Time* and *Thumb* showed decreasing accuracy in the top cluster.

Subjective Preferences

Based on a Condorcet ranking, the most liked gesture is *Dwell Time*, followed by *Fingers*, *Pinch*, *Fist*, and *Thumb*. Thus, although *Thumb* performed very well in terms of retrieval offset, participants did not like it, probably because it was a rather artificial movement. All gestures were rated to cause appropriate **mental load** ($median = 3$ on a 5-point Likert scale ranging from "too low" to "too high") and **physical effort** was rather low ($median = 2$) for all gestures. **General comfort** and **ease of accurate pointing** was perceived better for *Dwell Time*. *Pinch* and *Fingers* ($median = 2$ on a 5-point Likert scale ranging from "very easy/pleasant" to "very uneasy/unpleasant") compared to *Fist* and *Thumb* ($median = 3$).

8.2.5 Lessons Learned

With the Unadorned Desk 3D we extended the Unadorned Desk 2D to investigate how people would use off screen space in 3D. We were able to confirm some results that we already found for 2D off-screen interaction and added findings on selection gestures and general interaction in 3D.

Envisioned Applications

We envisioned several applications, inspired from previous work and application ideas for the Unadorned Desk 2D, which would benefit from the 3D interaction volume. The first application offers instant messaging control, similar to the Unadorned Desk 2D, states can be changed in off-screen space, however, instead of independently placing states on the desk, we stack them as they are semantically related. Additionally we can offer a second stack holding favorite contacts. By selecting them in off-screen space a conversation can be initiated. Similarly a media player can be controlled in off-screen space by offering the most important features such as start and stop in the plane (or directly on the desk if Unadorned Desk 2D and 3D would be merged) and continuous controls such as volume control or seeking in the currently played song or video can be implemented as stack. Moreover for a graphics editing program such as Photoshop, different tools can be stored in off-screen space and the vertical axis can be used to adjust certain parameters (e.g., the size of the brush tool). Finally, different applications can be stored in off-screen space and different instances of the same application (e.g., several browser tabs) can be stacked.

Summary and Limitations

Similar to the Unadorned Desk 2D we found that participants generally made use of the available two volumes to space items. Further they again arranged items in an imaginary grid but preferred locations closer to the desk and mostly only used the vertical axis if they had to place more items. We assume this might be partly due to missing landmarks for higher locations to aid spatial memory and potential fatigue of the arms. Both issues should be less severe on a regular desk, which most likely is not empty thus offering more landmarks. Moreover in contrast to the study, we expect that people use the off-screen space for small side interactions, hence not constantly interacting like in the study and thus not experiencing fatigue. Concerning gestures, we found (more) steady gestures (*Dwell Time* and *Thumb*) to perform better for retrieval. Especially *Dwell Time* was very well received by our participants.

This exploration suffers from similar limitations as the Unadorned Desk 2D. We only aimed at a lower bounds investigation, thus we did not offer a primary task to be carried out in parallel. Additionally, miniaturization of the tracking device would be needed to deploy it in real life. Moreover we did not offer any feedback. While participants still were able to retrieve most items, they were completely lost in case they forgot the placement. Thus, for a real life deployment, some kind of feedback – maybe only on demand in case of a forgotten placement – needs to be available. Nevertheless, generally participants successfully stored and retrieved items in off-screen space.

Generalizable Findings for Peripheral Interaction

The extension into the third dimension confirmed the previous findings and added new ones, especially concerning selection gestures.

Interaction based on Spatial Arrangements: Similar to the Unadorned Desk 2D, all participants made use of spatial arrangements (based on grids) to organize their items. These spatial arrangements were independent of the current selection gesture.

Handedness: In contrast to the Unadorned Desk 2D we not only offered one interaction area, but both interaction volumes in parallel left and right of keyboard and mouse. Participants nearly equally made use of both. For a smaller number of items, there seems to be a slight preference for the right interaction area. However, when analyzing placement and retrieval we did not find any difference in terms of locations and offset. Thus we believe both sides, and thus both hands – dominant and non-dominant – can perform this interaction equally well. As previously stated, participants most likely just need to get used to carry out tasks with their non-dominant hand, too [11].

Item Size: To explore the necessary size for a virtual item we analyzed the offset to the items location (x,y,z-coordinate). However, in a deployment of the system, items should have a predefined shape (most likely a sphere for 3D interaction volumes), for instance to ensure that items cannot be placed too close together. Only when performing a gesture inside such a sphere, the selection should be triggered, thus also minimizing erroneous selections. For all selection gestures we found that a sphere with the radius of 80 mm would lead to 95% of correct retrievals. This is in line with the Unadorned Desk 2D were we found 85 mm as maximum. However, for the most liked gesture *Dwell Time* a radius of only 50 mm would perform equally well.

Location: As already stated, generally both interaction volumes worked equally well. However inside the interaction volumes we found different locations being more suitable than others. Participants preferred to locate items close to the desk. This location also performed better in terms of retrieval offset. Vertical axis were mostly used if participants were asked to store more items in off-screen space to ensure enough spacing. Letting users place their items on their own aids their memorization of item locations [98]. However, in case application designers need to predefine locations, our observations suggest to rely on the bottom plane (probably directly on the desk as in the Unadorned Desk 2D) and use the vertical axis for stacks of semantically related item (e.g., several browser tabs).

Gestures: The Unadorned Desk 3D introduced selection gestures to distinguish between input to the system and regular movement on the desk. Gestures did not affect placement of items, however we found a difference when retrieving items. More steady gestures (*Dwell Time* and *Thumb*) did perform better in terms of retrieval offset. We believe the reason is the difference between the perceived location and the tracked location. For *Fist* the perceived location is probably based on the fingertips while locating to the correct item. However, when forming a fist and thus performing the gesture, the knuckles are tracked. Similar effects are caused by *Pinch*. In contrast, for *Dwell Time* – the most preferred gesture – the point of selection (the fingertip) is always visible. Holding the hand steady might also impose less cognitive load although it includes a predefined waiting time. However, participants were not bothered by that. Moreover, as already suggested, when merging the Unadorned Desk 2D and 3D and thus also using the desk's surface as storage again, *Dwell Time* also blends well with the touch gesture of the Unadorned Desk 2D.

Chapter 9

Evaluating Peripheral Interaction

Synopsis

Peripheral interaction is mostly evaluated through in-situ deployments up to now, which offer the possibility to move the interaction to the periphery and integrate it into daily routines. However using only in-situ deployments neglects the iterative design process, which aims at evaluation during different stages of a prototype. To close this gap we propose a lab study methodology for a desk- and computer-based scenario. In a case study we compared the results of the in-situ deployment of the Peripheral Music Controller (cf., Chapter 7.1) to the results of a lab evaluation with our methodology and found comparable results. We thus consider our lab study methodology a valid approach to assess the quality of early prototypes. To further investigate the study methodology itself and to offer a reference frame for results, we evaluated six everyday tasks (drink, food, light, note, TV, talk) and found that they tended to cause less disruption in the primary task than the digital peripheral tasks, however only marginally. With the everyday tasks being well known and thus well trained, we believe this rather supports our peripheral tasks. Overall, we want to stress that we do not argue for lab-based experiments to replace in-situ deployments but to use them both to enrich the evaluation of peripheral interaction thus improving devices designed for peripheral interaction.

Dey and De Guzman state that "peripheral displays are notoriously difficult to evaluate as most evaluation techniques draw attention to a display making it no longer peripheral" [63]. This obviously not only holds true for peripheral or ambient displays but also for peripheral interaction as it is supposed to blend into the daily routines and be carried out in the attentional periphery, without focusing on it.

This chapter addresses evaluation of peripheral interaction by reviewing literature on evaluation of peripheral interaction but also on evaluation in related fields such as ambient information and multitasking. Moreover we propose an evaluation strategy for the lab and verify it by comparing results for the Peripheral Music Controller (cf., Chapter 7.1) from the lab evaluation with the independently conducted in-situ deployment. Additionally we evaluate typical physical but habituated tasks (such as drinking, eating, switching on lights) with this lab evaluation method as reference.

9.1 Design Process for Peripheral Interaction

The iterative design process [183] (cf., Figure 9.1) serves as basis in human-computer interaction for many projects and is intended to be run through several times during different stages of the development of a prototype or product. Low fidelity prototypes such as paper prototypes or sketches are used in the early stages [29]. These early prototypes can be used to decide between different designs and uncover conceptional usability issues through cognitive walk-throughs or as inspiration in focus groups. However, as they are not yet working prototypes they cannot be deployed in a everyday setting and thus they cannot blend into daily routines or habituated actions. Moving from low fidelity prototypes to high fidelity prototypes, testing usually is carried out via lab evaluations or field deployments [64].

However, when reviewing work in the field of peripheral interaction, one evaluation type is prevailing: most projects are only evaluated at the end of the design process through an in-situ deployment (e.g., [25, 26, 70]). While we completely agree that this is a suitable and important approach for peripheral interaction, as it offers the necessary time to get used to a new system and integrate it into the daily routines, we also believe that there is a need to explore other forms of evaluation, especially for early testing in the lab. As first step to

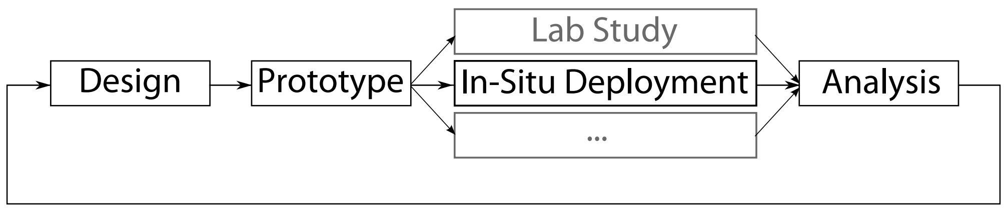

Figure 9.1: The iterative design process is usually run through several times for different development stages. Currently, for peripheral interaction mostly in-situ deployments are carried out neglecting other evaluation methods (grey boxes), especially for early design phases.

integrate evaluation in the early design phases, we used design sketches to select the design of the Appointment Projection (cf., Chapter 6.2.2) and applied paper prototypes to find the most suitable gestures for the Peripheral Music Controller (cf., Chapter 7.1.2). Once we deployed the Peripheral Music Controller in an eight-week in-situ deployment, we found that the selected gestures were very well suited, thus the paper prototype based study was successful. However, during the in-situ deployment we also uncovered tracking issues for freehand gestures, which we most likely would have detected in a lab testing, if we would have conducted one, and thus eventually would have come up with even more meaningful results in the field, because tracking would not have been an issue anymore.

While obviously the iterative design process also forms a good basis for developing prototypes for peripheral interaction, there is a huge lack in terms of evaluation methods to use at different stages, as traditional methods often do not work because peripheral interaction is usually not targeting the primary task and should not be in the focus. The following sections reviews evaluation for peripheral interaction as well as evaluation in related fields such as ambient information and multitasking. Finally we derive a lab evaluation method that can be used to gather first insights on the general feasibility of a device and uncover usability problems before deploying systems for several weeks.

9.1.1 Evaluation in Peripheral Interaction

Evaluation of a prototype for peripheral interaction up to now was mostly conducted through in-situ deployments except for one project (PolyTags [189]), which was evaluated in the lab.

In-Situ Deployments

As stated, most projects in the field of peripheral interaction have been evaluated with the help of in-situ deployments. Table 9.1 gives an overview on all existing deployments based on related work (cf., Chapter 4.4.1) and prototypes presented in this thesis (cf., Part II).

Researchers state to evaluate through in-situ deployments to observe the usage of the devices in the actual context of use [26] as interaction can only shift to the periphery if it is integrated in daily routines [23]. Additionally, old habits sometimes have to be unlearned and the new device has to be adopted for this task, which also needs time [19]. Generally, using in-situ deployments is inspired by related work in the field of ambient information systems [26, 101], which also depends on evaluation in a real world context [110]. However, experimenters usually did not tell the participants, that they expected the device to shift to the periphery [26].

Overall, all in-situ deployments lasted between two and eight weeks and were conducted with two to eight participants. Participants were always interviewed by the experimenter and complementary questionnaires were used. In contrast, observation of participants was only done rarely (usually at the end of the deployment) and only for a limited time (e.g., 30-45 minutes) [26] as it reminds the user about the tested system and thus it might shift

Table 9.1: Overview of in-situ deployments in the field of peripheral interaction: *Task Management System* (= TMS), *NoteLet*, *FireFlies* (all summarized in Chapter 4.4.1), *StaTube*, *Appointment Projection* (= AP), and *Peripheral Music Controller* (= PMC).

	TMS [69, 70]	**NoteLet** [26]	**FireFlies** [23, 25]	**StaTube** Ch. 6.1	**AP** Ch. 6.2	**PMC** Ch. 7.1
Duration (in weeks)	5	2	6	2 (+ 1 as baseline)	2	8 (2 per device)
Participants	3	2	6	6	3	8
Interviews	✓	✓	✓	✓	✓	✓
Questionnaires			✓	✓	✓	✓
Observations		✓	✓			
Logging	✓	✓		✓	✓	✓

to the foreground [110]. If possible logging was included to capture the usage of the device. For later comparison, logging of task related behavior before the deployment was also included [101].

Controlled Lab Experiments

The only lab-based evaluation from related work was conducted for PolyTags by Olivera et al. [189]. The study setup was based on a dual-task scenario. As distraction participants (overall 10 participants took part) were asked to count the number of occurrences of a specific vowel in a text. While counting they were randomly interrupted to interact with either PolyTags or a GUI, which offered the same functionality as PolyTags (e.g., to change the status on Twitter or controlling an intelligent environment). Olivera et al. measured the error rate and the overall performance and found that participants were significantly more efficient and made less errors when using PolyTags instead of the GUI and thus they conclude, that PolyTags imposed less mental load on the participants and could be performed more easily in parallel to another task.

In this thesis, we conducted lab studies relying on dual task setups. For the Appointment Projection we used typing as primary task, which generally did work, but was very dependent on previous training and also did not offer any incentive to perform well, as typing did not include a gamification approach to motivate faster or more correct typing. Thus, for follow up studies we aimed at a more generic approach, which development we will describe in more detail in Chapter 9.2. This methodology was then used to evaluate Interaction Styles & Feedback (cf., Chapter 7).

Finally, we conducted lab studies with the Unadorned Desk (Chapter 8) but refrained from using a dual task setup, as we aimed at a lower bounds investigation, exploring parameters and general feasibility for building a system, which could be evaluated now with a dual task setup or through in-situ deployments.

9.1.2 Evaluation in Related Fields

As work in the field of peripheral interaction is limited, especially in the scope of lab evaluations we analyzed evaluation strategies in related fields such as ambient information systems, which also address the periphery of attention [197], multitasking, which targets dual-task situations as well as interruption management [60, 162] and more in general ubicomp technology, which is designed to blend into the environment [48, 53]. All of these fields deal with problems, for instance the system, which is evaluated, is not addressing a task-oriented purpose or is "only" used alongside another task, thus the less important task in a dual-task setup is the more important task in the study [161].

This review on related literature can only give a glimpse into different evaluation approaches and thus only focuses on evaluation of a prototype (low or high fidelity) but leaves out methods for user research such as for example context mapping studies [22] or contextual field research [53].

In-Situ Deployments

Especially in the field of ambient information systems (cf., Chapter 4.3) many researchers argue for in-situ deployments. Ambient systems are designed to blend into the environment [241] and direct observation of participants would steer their attention to the system and thus not reveal the actual use of the prototype [110]. Additionally, only in-situ deployments can inform about long term adoption and usage of a new system [241]. This imposes several challenges on researchers, which are also true for the evaluation of peripheral interaction. Although peripheral interaction – in contrast to ambient information [110] – usually targets some kind of task, the interaction itself should be carried out with minimal attention, thus at best users do not focus on it and therefore most likely do not remember it well and cannot reflect on it in a follow up interview [110]. Generally, an important question to answer is how much observation is reasonable. On the one hand, too close observation might influence participants, on the other hand, a certain level of observation is necessary to obtain meaningful results [110].

Data collection during deployments is carried out by different means: Some researchers rely on randomly appearing pop-ups, which ask for user feedback [121], others schedule interviews [222]. Logging is included, if possible also beforehand to see behavior changes when installing the system [241]. Overall, a combination of methods, such as proposed by Shneiderman and Plaisant [221] and their multi-dimensional in-depth long-term case studies (MILCs), seems to be a suitable approach. However, researchers are still not in control of events that occur or do not occur during an in-situ deployment and thus might miss interesting findings. Hazlewood et al. therefore propose to add some artificial events that might trigger interesting behavior [110]. Nevertheless, when deploying a system in the participants' personal environment, maintaining the participants' privacy is very important, especially when including automated logging [241].

Last but not least, to conduct an in-situ deployment, one needs to have a working prototype, which is reliable and robust [241], as otherwise bugs might hinder regular usage and damage the results. In some cases the problem can be overcome by a Wizard-of-Oz approach (cf., the CareNet Display [54]), however, even if this is possible, the participants should have the feeling, that the prototype they are testing is fully functional. Hence, in-situ deployments are usually not possible during early stages of development.

Controlled Lab Experiment

As previously stated, in-situ deployments can only be achieved if a working prototype is available. Additionally, in-situ deployments offer insights on the usage of a system in the actual environment, however, they limit researchers in their observation. To gather first results, especially on the quality of the implementation [108] lab explorations are an important first step in the development process of a new device. To evaluate ambient information in the lab or more generally to evaluate multitasking behavior, which we also target with peripheral interaction, usually dual task scenarios are applied. Thus, a primary task alongside the secondary task (in our case the secondary task is the peripheral task) is introduced to distract the participants and move the secondary task to the background or periphery [108].

Different primary tasks have been used by researchers, among them *mathematical tasks* (e.g., calculating or counting) [17, 121] or *comprehension tasks* (e.g., reading texts, analyzing graphs or answering quizzes) [17, 165, 217]. Moreover *typical interfaces* have to be operated (e.g., registration forms, sorting emails) [17, 163, 165, 217] or *playful tasks* are used (e.g., playing Tetris or other click tasks) [90, 218]. Finally, sometimes rather *complex tasks*, which consist of several steps, are used such as reading an email, acquiring information about it and replying to this email [37].

To evaluate the interplay between both tasks, metrics such as task completion time and error ratio (usually compared to the baseline, thus interaction with the primary task without disruption by the secondary task [264]) but also interruption and resumption lag and general response time are calculated [17, 37, 90]. The amount of performance drop is used to assess the interference of primary and secondary task. Moreover emotional distress such as annoyance or anxiety are sometimes measured [17, 163]. To assess awareness, comprehension and aesthetics (especially for ambient information systems) questionnaires or interviews are conducted after having finished the given task [165, 218]. Psychology also includes physiological measurements such as the diameter of the pupils to assess how engaging a task is [141, 255]. However, human-computer interaction usually refrains from that.

Analytical Methods

There are some analytical methods, which do not necessarily rely on participants but on experts inspecting the design. For ambient information systems, Mankoff et al. [161] developed heuristics, which are based on Nielsen's and Molich's [184] heuristics but are especially modified to target issues of ambient information, such as "peripherality of display". For notification systems, McCrickard et al. [171] developed the IRC-Framework, which is designed to classify notification systems along the axes interruption, reaction and comprehension.

9.2 Designing a Controlled Lab Study for Peripheral Interaction

The review of related work showed that in-situ deployments are well established in the field of peripheral interaction. However, experience with lab studies is limited, although they might enhance the design process for peripheral interaction especially for early phases. We set out to design a lab-based evaluation method. Obviously, this one method by far cannot cover the whole spectrum of possible evaluation strategies. However we contribute one evaluation method and show, which aspects we could successfully test in the lab.

Lab-based studies in related fields usually make use of dual task situations, thus they combine a primary task, which is intended to be in the focus of attention of the participant, and one secondary task that is performed alongside. In our case the secondary task is the peripheral task, which is supposed to be evaluated. Thus we need to design a primary task.

9.2.1 Designing the Primary Task

When designing a primary task for evaluation[1] [106] one needs to keep in mind that the primary task will impact the measurement of the secondary task. Thus it is feasible to use a primary task that is close to a everyday situation, however, it should be abstract enough to control and especially measure attention and distraction. We analyzed different properties for primary tasks and propose a list of four parameters that should be defined for any primary task before conducting a study. Parameters can be fixed but also vary during an evaluation depending on the peripheral task and the goal of the evaluation.

Input Channel: Depending on the intended everyday use case the input channel for the primary task should be chosen. Thus input for a computer- and desk-based scenario might be traditional input devices such as mouse and keyboard, however many others can be imagined (e.g., body movements, unimanual vs. bimanual). The input channel to some extent blocks the associated senses or body parts (e.g., hands) for secondary tasks.

Output Channel: Similar to the input channels, one should choose output channels for the primary task based on the expected everyday use case. For computer- and desk-based

[1] Chapter 9.2 and Chapter 9.3 are based on: Hausen, D., Tabard, A., von Thermann, A., Holzner, K., and Butz, A. Evaluating Peripheral Interaction. In Tangible, Embedded and Embodied Interaction (TEI), ACM, 2014, 21-28.

scenarios typical output channels are visual (through the display), auditory and/or haptic. Again these channels are to some extent blocked to be used by the secondary task.

Input Interruptibility: Describes the degree of continuous input to the primary task. Thus it also ranges from low input interruptibility – participants need to constantly attend to the primary task – and high input interruptibility – participants may take breaks at their own liking to carry out other secondary actions. Input interruptibility can also be influenced by offering clear subtask boundaries, which facilitate transitions to secondary tasks [16, 255].

Attentional Interruptibility: Describes the degree of continuous attention required to execute the primary task. Thus it describes the harm of shifting the attention away from the primary task. Primary tasks can range from low attentional interruptibility – an attentional shift away from the primary task has a huge negative effect on the overall performance in the primary task – and high attentional interruptibility – an attention shift only has a marginal negative effect on the primary task.

The design dimensions for primary tasks are intentionally very general and abstract to be reused for the design of other primary tasks. Input and attentional interruptibility describe the difficulty of a task. Depending on the expected everyday task and the secondary or peripheral task the parameters should be adjusted. Moreover, additional parameters should be taken into account depending on the expected everyday task, such as experience and motivational factors. Thus, a large variety of primary tasks can be imagined. However here, we focus on a standard desktop PC scenario, which is still a very common way of interacting with digital data and many side tasks are present while working on a computer.

9.2.2 Preliminary Experiment

As we decided to design an evaluation method for a desk- and computer-based scenario, *input* and *output channel* are given. Input will rely on mouse and keyboard, at best as bi-manual input, as mouse and keyboard in a everyday scenarios are also often used in parallel. Output will be visual only, as audio in office scenarios is often considered to be disturbing, especially for co-workers. *Input interruptibility* and *attentional interruptibility* are harder to define. Thus we designed two tasks – one event-based and one continuous – and performed a preliminary experiment to assess the suitability of both tasks.

Both tasks are inspired by Square Click [218, 219]. When "playing" Square Click, a black square appears at random locations every second. Participants need to click on this square within one second to score a point. We modified this task to offer a bit more freedom during task execution, thus we slightly increased attentional and input interruptibility.

Event-Based Primary Task

We designed the first task with low attentional interruptibility and low input interruptibility, thus participants had to react to events similar to Square Click. We introduced several items differing in shape (triangle, square, circle) and color (blue, green, pink). They appear in randomized order at randomized locations at randomized times (see Figure 9.2 left). To remove them from the screen participants have to press a corresponding number on the number pad (see Figure 9.2 right).

To get preliminary insights we asked four researchers from our lab to take part in a study. They had to carry out the event-based task alongside an artificial peripheral task (thus no meaningful task was associated with the peripheral device, they were just asked to turn a device according to the color that lights up). All four participants did not know that we were actually interested in the primary task. Afterwards we invited them to a group discussion and uncovered two problems: (1) the task was not perceived as engaging or motivational. Instead they considered it tiring and monotonous as there appeared gaps with nothing to do and no encouraging feedback was given. (2) Moreover the task gave them no freedom to develop strategies. They were either stressed out because items appeared and the peripheral task also asked for attention or they were bored when nothing happened. Most of these problems are due to the event-based character. Consequently we built a second, continuous task, which also resembles traditional computer-based tasks better, as they usually are not that time critical.

Continuous Primary Task

Based on the feedback we designed a second – continuous and round based – task, thus with high attentional and high input interruptibility. For every round 30 items are randomly displayed on screen in different colors and shapes (see Figure 9.2 middle). We furthermore

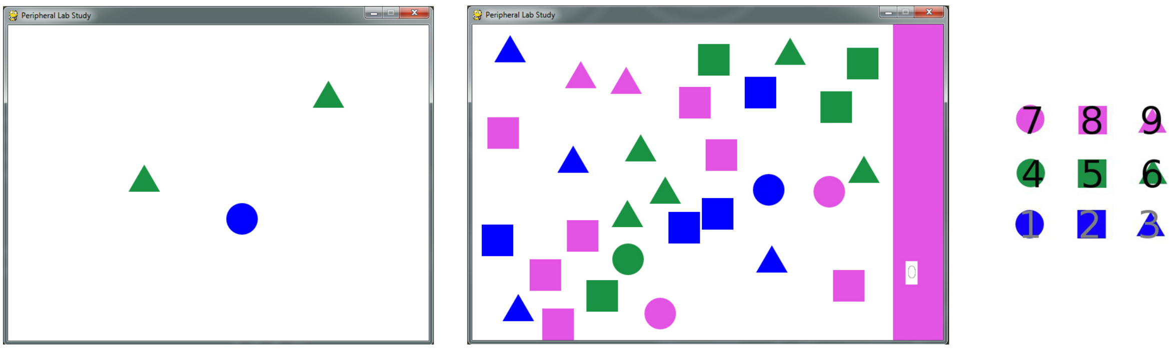

Figure 9.2: Left: *Event-Based Primary Task* – Shapes appear randomized and should be removed; Middle: *Continuous Primary Task* – Shapes of one given color should be removed (here pink), when all items of the given color are removed the area is filled again with items and a new color is randomly determined; Right: Shape and color combinations mapped to the number pad. The corresponding number for each shape has to be pressed to remove it.

included bimanual interaction, thus for items in the color depicted in the right bar, pressing the corresponding number for each shape/color combination and clicking on it removes the item. Once all items of the given color are removed a new round starts immediately, thus new items appear randomly on screen. Additionally we added a counter displaying the number of correctly removed items as motivation.

This task now leaves room for different strategies. Users can for example remove all items of the same shape, thus not changing the key they press but moving the mouse over longer distances. In contrast they can also opt to click on close by items but change the number key frequently. Moreover, they still can react immediately to the peripheral task, but they can also decide to finish removing all items of one shape, or finishing one complete round (one round approximately lasted 10 seconds) before attending to the peripheral task.

Again we conducted a small study with eight participants (one female), who were on average 22 years old. We told them that we were interested in the peripheral device. We reused StaTube (cf., Chapter 6.1) but with an artificial task, thus participants were asked to turn the upmost level to match the color of the lower levels when they light up). Participants were seated at a standard table equipped with display, keyboard, mouse and of course the peripheral device. Additionally we attached a sheet showing the mapping of shapes and colors (see Figure 9.2 right) to the keyboard.

Participants first were introduced to both tasks and then carried out the primary task for five minutes for baseline measurement. Afterwards they conducted the study with both tasks for five minutes. We logged all interactions (e.g., removed items and errors) and took notes on focus shifts, hand movements and other observations.

We found that the peripheral device did not shift to the periphery, however, we found usability problems about the device, thus we believe the designed lab study can be a useful addition to the design process of peripheral interaction in early stages. Moreover, we found a degradation of performance in the primary tasks. Assuming the peripheral device, which causes the least degradation is the best, the study can also be used to decide, which of different early designs to pursue.

9.2.3 Implementation

The primary task was implemented in Python and Pygame with different classes for the primary as well as the secondary task to offer maximum flexibility when adjusting the method for different secondary tasks. Log data consists of the number of removed items, the number of completed rounds, errors in the primary task (wrong color, wrong key press) and peripheral task (wrong reaction to levels lighting up or no reaction to trigger), a time stamp of each click, and was written to a text file for later analysis.

9.3 Case Study: Comparing Results from the Field and Lab

To assess the validity of our lab study methodology we conducted a comparative case study[2] [106] with one of our prototypes – the Peripheral Music Controller (see Chapter 7.1). We invited two user groups to our lab: novice participants, who did not know the system, and experienced participants, who previously took part in the in-situ deployment of the Music Controller and thus were familiar with the devices. By comparing the results of both user groups we wanted to find out whether familiarization with the device would impact the results and thus render our study invalid. The lab study was developed in parallel to the in-situ deployment of the Music Controller, thus the results of the in-situ deployment did not affect the development of the controlled experiment. However, the lab study was conducted shortly after the in-situ deployment, hence experienced users still remembered all devices very well, but we were also aware of the results of the in-situ deployment at that point.

9.3.1 Procedure of the Controlled Lab Experiment

The prototype for the Peripheral Music Controller was not altered in any way since the in-situ deployment. However, interacting with the audio player while listening to music is usually intrinsically motivated, therefore users themselves decide when to skip a song or stop the player. In the lab we had to trigger these interactions. At random moments the music stopped to play during the evaluation. We instructed participants to start the music again whenever this happens (start/stop command). Moreover we added some noise, which was unpleasant to listen to, to some songs and told participants to skip the song whenever that happens (next/previous command). Finally we changed the volume noticeably and asked participants to change it back to a reasonable volume (volume command).

Participants

We invited two distinct user groups: Twelve *novice users* (five female), who never experienced our system before, thus resembling the typical participant in a lab study. They ranged in age between 20 and 30 (average age 22 years). Moreover, from the in-situ deployment, six of our eight participants returned (one female), who resemble *experienced users*. They ranged in age from 21 to 32 (average age 25 years). All participants stated to multitask and regularly listen to music on their computer. No participant reported any hearing impairments.

[2] Chapter 9.2 and Chapter 9.3 are based on: Hausen, D., Tabard, A., von Thermann, A., Holzner, K., and Butz, A. Evaluating Peripheral Interaction. In Tangible, Embedded and Embodied Interaction (TEI), ACM, 2014, 21-28.

Experimental Design and Procedure

We had a mixed-model design, with two independent variables (*interaction style* and *user group*) with every participant testing all interaction styles (graspable, touch, freehand and media keys) but only belonging to one user group (novice or experienced). To minimize learning effects we counterbalanced interaction styles. Participants were seated at a regular desk equipped with a display, keyboard and mouse as well as the respective devices that was investigated (see Figure 9.3). The peripheral device was located on the right side, as most participants preferred the right side during the in-situ deployment.

We introduced the participants to the (continuous) primary task and let them train the task. Afterwards they carried out the task for two minutes as baseline measurement. We then introduced the secondary task and thus the first interaction style. We carried out a two minute training with triggers for the peripheral task and told them to reduce gazing to the peripheral device if possible. Finally, participants carried out both tasks – primary and peripheral – in parallel for five minutes. We told participants to react to triggers in a reasonable time frame, thus leaving them room to adapt personal strategies in the primary task. Overall 16 triggers per round appeared at random intervals. Before continuing with the next interaction style we asked them to fill out a questionnaire. During the whole study we minimized the audio player (here iTunes), consequently participants only had inherent and functional feedback.

As dependent variables we recorded for the primary task the number of successfully *removed shapes* and the *error ratio* (errors – wrong shape/color – in relation to the overall number of removed items). For the peripheral task we calculated the *interruption lag* (time between the last interaction in the primary task and the start of the interaction in the peripheral task) and the *errors* (wrong gestures, gestures without trigger, no reaction to trigger, tracking error). Finally we analyzed participants *gazes* towards the peripheral device or media keys through video recordings. All Likert scales ranged from 1 = I totally disagree to 5 = I totally agree.

Figure 9.3: Participant during the study interacting with the freehand tracking device.

9.3.2 Results of the Controlled Lab Experiment

We analyzed the results from both user groups – novice and experienced – for the lab study and compared them, whenever possible, to the results from the in-situ deployment.

Quantitative Data for the Primary Task

We performed Two-Way Mixed ANOVAs. For pair-wise comparison, we used Bonferroni-corrected confidence intervals to retain comparisons against $\alpha = 0.05$. When the assumption of sphericity was violated, we used Greenhouse-Geisser to correct the degrees of freedom. All unstated p-values are $p > 0.05$.

Performance: As indicator for performance in the primary task we counted the correctly removed shapes in the primary task. We did not find any significant effect for *Interaction Style* × *User Group*. However, *Interaction Styles* did have a significant impact on performance on the primary task ($F_{3,48} = 8.453, p < 0.001$). Post hoc test showed that performance was better when interacting with the *Graspable* device in the periphery than with *Freehand* interaction and *Media Keys* ($p = 0.004$). As Figure 9.4a indicates, the most correct shapes in the primary task were removed with the *Graspable*, followed by *Touch*, *Media Keys* and *Freehand*. Table 9.2 states the means and standard deviations for all interaction styles for experienced and novice users.

Error Ratio: We calculated the error rate as ratio between all errors in the primary tasks and all successfully removed shapes. However we did not find any significant effect for neither *Interaction Style* nor *User Group*. However, Figure 9.4b shows that interaction through *Touch* caused slightly more errors than *Media Keys*, *Freehand* and *Graspable*. Again, Table 9.2 states the means and standard deviations.

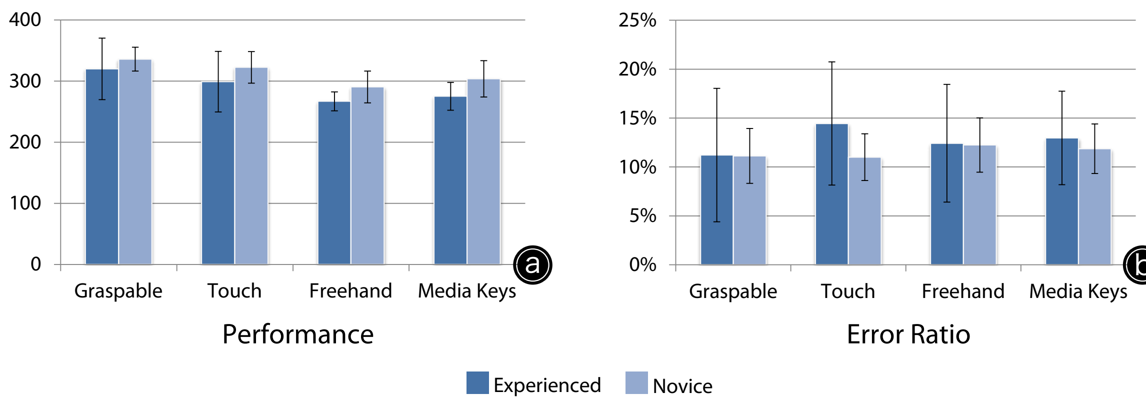

Figure 9.4: Quantitative data for the primary task: (a) performance measured as number of removed shapes in the primary task; and (b) error ratio (errors in relation to overall removed shapes). Error bars indicate 95% confidence intervals.

Table 9.2: Means and standard deviation for all quantitative data. (PT = Primary Task; ST =Secondary/Peripheral Task.) Best rating highlighted in bold.

	Graspable		Touch		Freehand		Media Keys	
	Exp.	Nov.	Exp.	Nov.	Exp.	Nov.	Exp.	Nov
Performance (PT)	m=320.0 sd=62.7	**m=335.9 sd=43.4**	m=299.2 sd=61.8	m=322.5 sd=45.6	m=266.8 sd=19.2	m=290.4 sd=45.9	m=275.2 sd=28.5	m=303.8 sd=52.6
Errors (in %) (PT)	m=11.2 sd=0.85	m=11.1 sd=5.0	m=14.4 sd=7.9	**m=11.0 sd=4.2**	m=12.4 sd=7.5	m=12.2 sd=4.9	m=13.0 sd=6.0	m=11.9 sd=4.5
React. Time (in sec) (ST)	**m=1.66 sd=0.34**	m=1.97 sd=0.45	m=1.74 sd=0.31	m=2.04 sd=0.72	m=2.58 sd=0.63	m=2.31 sd=0.47	m=2.02 sd=0.43	m=2.09 sd=0.74
Errors (ST)	m=2.33 sd=1.97	m=1.08 sd=0.79	m=5.83 sd=2.93	m=3.42 sd=2.11	m=3.83 sd=2.14	m=3.42 sd=1.73	**m=0.67 sd=0.52**	m=1.00 sd=1.54
Gazes (in %) (ST)	m=32.0 sd=29.1	**m=29.5 sd=22.9**	m=49.4 sd=39.7	m=79.2 sd=32.2	m=9.6 sd=14.1	m=80.1 sd=24.3	m=100 sd=0	m=100 sd=0

Quantitative Data for the Peripheral Task

Similar to the primary task we also conducted Two-Way Mixed ANOVAs for the quantitative data measured in the peripheral task.

Interruption Lag: As interruption lag we calculated the time between the last interaction in the primary task and the start of the interaction in the peripheral task. We did not find any significant effect for *Interaction Style* × *User Group*. However we found a significant effect for *Interaction Styles* ($F_{3,48} = 8{,}243$, $p < 0.001$). Post hoc tests showed that *Freehand* causes a significantly longer interruption lag than *Touch* and *Graspable* ($p = 0.004$). Figure 9.5a further indicates that the interruption lag was shortest for *Graspable* followed by *Touch*, *Media Keys* and *Freehand*. Table 9.2 lists the corresponding means and standard deviations.

Errors: We counted the errors (wrong gesture, gesture without trigger, no reaction to trigger, tracking errors) in the peripheral task and did not find any significance for *Interaction Style* × *User Group*, but for *Interaction Styles* ($F_{3,48} = 14.863$, $p < 0.001$). Post hoc tests revealed that *Graspable* interaction caused significantly less errors compared to *Touch* and *Freehand* ($p = 0.03$) and *Media Keys* compared to *Touch* and *Freehand* ($p = 0.003$). Figure 9.5b shows that overall the least errors appeared with *Media Keys* followed by *Graspable*, *Freehand* and *Touch*. Table 9.2 again states the respective means and standard deviations.

Gazes: As we aimed at interaction, which can be carried out with minimal visual attention we analyzed the gazes to the devices but did not find a significant difference for *Interaction Style* × *User Group*. However, we found a significant effect for *Interaction Styles* ($F_{1.821,29.133} = 28.540$, $p < 0.001$). Post hoc tests revealed that participants gazed less at

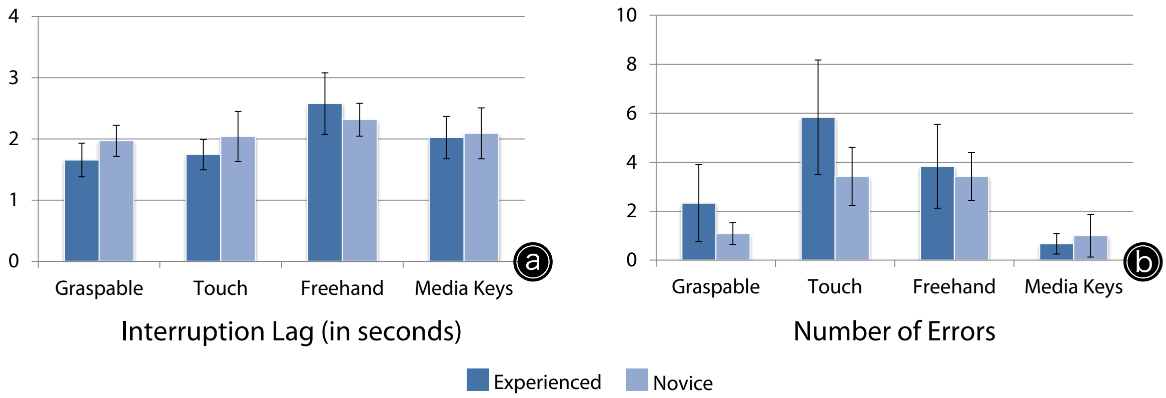

Figure 9.5: Quantitative data for the peripheral task: (a) interruption lag in seconds (from last interaction in primary task till interaction in the peripheral task); and (b) number of errors in the peripheral task. Error bars indicate 95% confidence intervals.

the *Graspable* device during interaction than at the *Freehand* tracking and the *Media Keys* ($p < 0.001$). Moreover, they gazed less at the *Touch* device than at the *Freehand* tracking and the *Media Keys* ($p = 0.047$). Most interestingly, participants gazed at the *Media Keys* for every single interaction.

Subjective Data

Quantitative data could not be directly compared to the in-situ deployment as (for privacy reasons) we did not log anything about the primary task. Moreover as motivation was intrinsically there was no trigger to abide to. However, the questionnaire in the lab study was similar to the in-situ deployment we are able to compare subjective ratings.

All devices were considered to be **easy to learn** (for all *User Groups* and *Interaction Styles* *median* = 4 or higher), with *Graspable* (In-Situ/Exp: *median* = 5; Nov: *median* = 4) and *Touch* (All: *median* = 4) being the most **enjoyable**. In contrast *Media Keys* (All: *median* = 3) and *Freehand* (In-Situ: *median* = 4; Exp: *median* = 2.5; Nov: *median* = 3) are moderately enjoyable. Distribution of answers is shown in Figure 9.6.

Assessing how peripheral the interaction was perceived, we found that **mental load** was low in all user groups for *Graspable* (In-Situ/Exp: *median* = 5; Nov: *median* = 4) and *Touch* (In-Situ: *median* = 5; Exp: *median* = 4.5; Nov: *median* = 4). However, *Freehand* interaction was stated to be more mentally demanding in the lab than in the field (In-Situ: *median* = 5; Exp: *median* = 3; Nov: *median* = 2.5), in contrast, *Media Keys* were perceived less demanding in the lab than in the field (In-Situ: *median* = 2.5; Exp: *median* = 3.5; Nov: *median* = 4). **Distraction** was considered rather low for *Graspable* (In-Situ/Exp: *median* = 4.5; Nov: *median* = 4) and *Touch* (In-Situ: *median* = 3.5; Exp/Nov: *median* = 4), but a bit higher for *Freehand* and *Media Keys* (Both: *median* = 3). Being asked whether they felt they could interact **without looking** at the device, they confirmed it for *Graspable* (In-Situ/Nov: *median* = 5; Exp: *median* = 4.5) and *Touch* (In-Situ/Nov: *median* = 4; Exp:

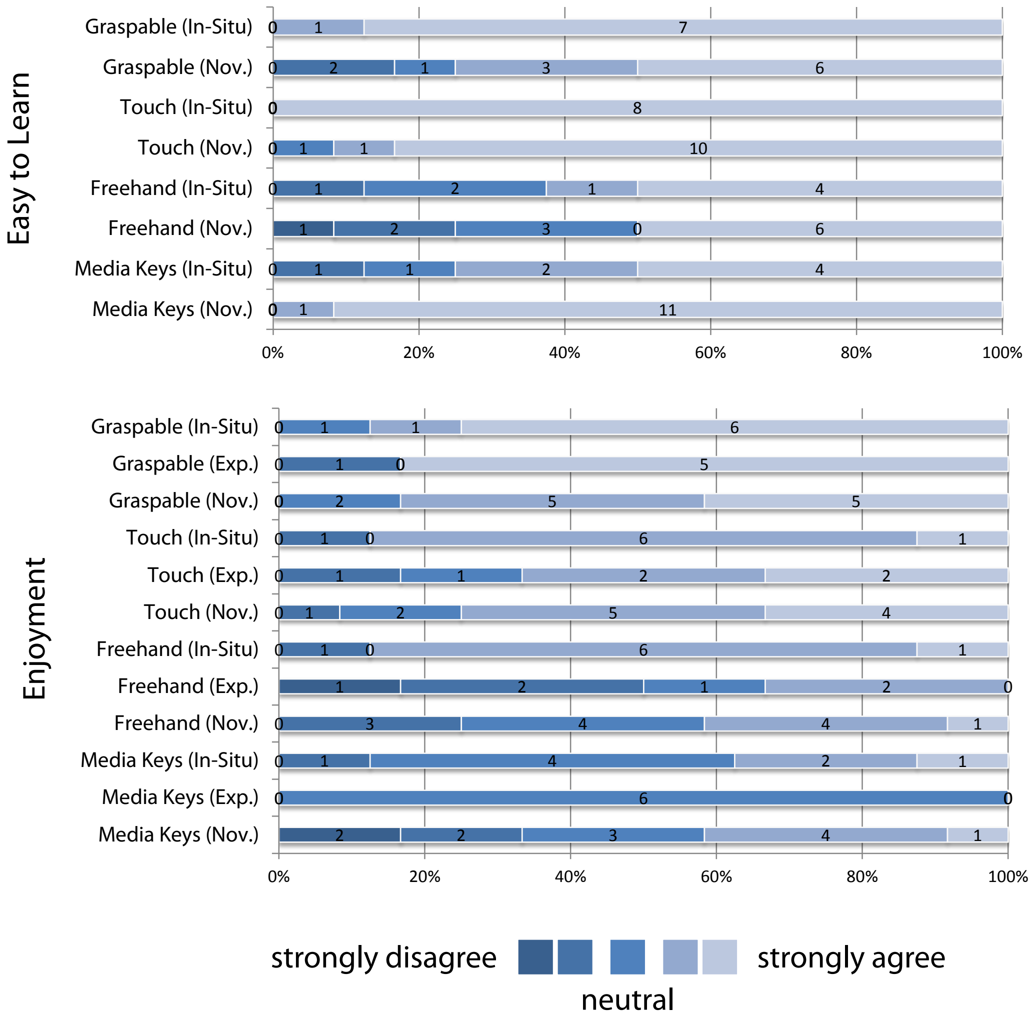

Figure 9.6: Likert scales for *learnability* and *enjoyment*.

median = 3.5) but not so much for *Freehand* (In-Situ: *median* = 2.5; Exp: *median* = 3; Nov: *median* = 2) and *Media Keys* (In-Situ: *median* = 2.5; Exp/Nov: *median* = 2). Distribution of answers is summarized in Figure 9.7.

Participants did not feel like their **performance** in the primary task was affected much by *Graspable* interaction (Exp: *median* = 2; Nov: *median* = 2.5) but increased from *Touch* (Exp: *median* = 2; Nov: *median* = 3) to *Freehand* (All: *median* = 3.5) and *Media Keys* (Exp: *median* = 4; Nov: *median* = 3). Distribution of answers can be viewed in Figure 9.8

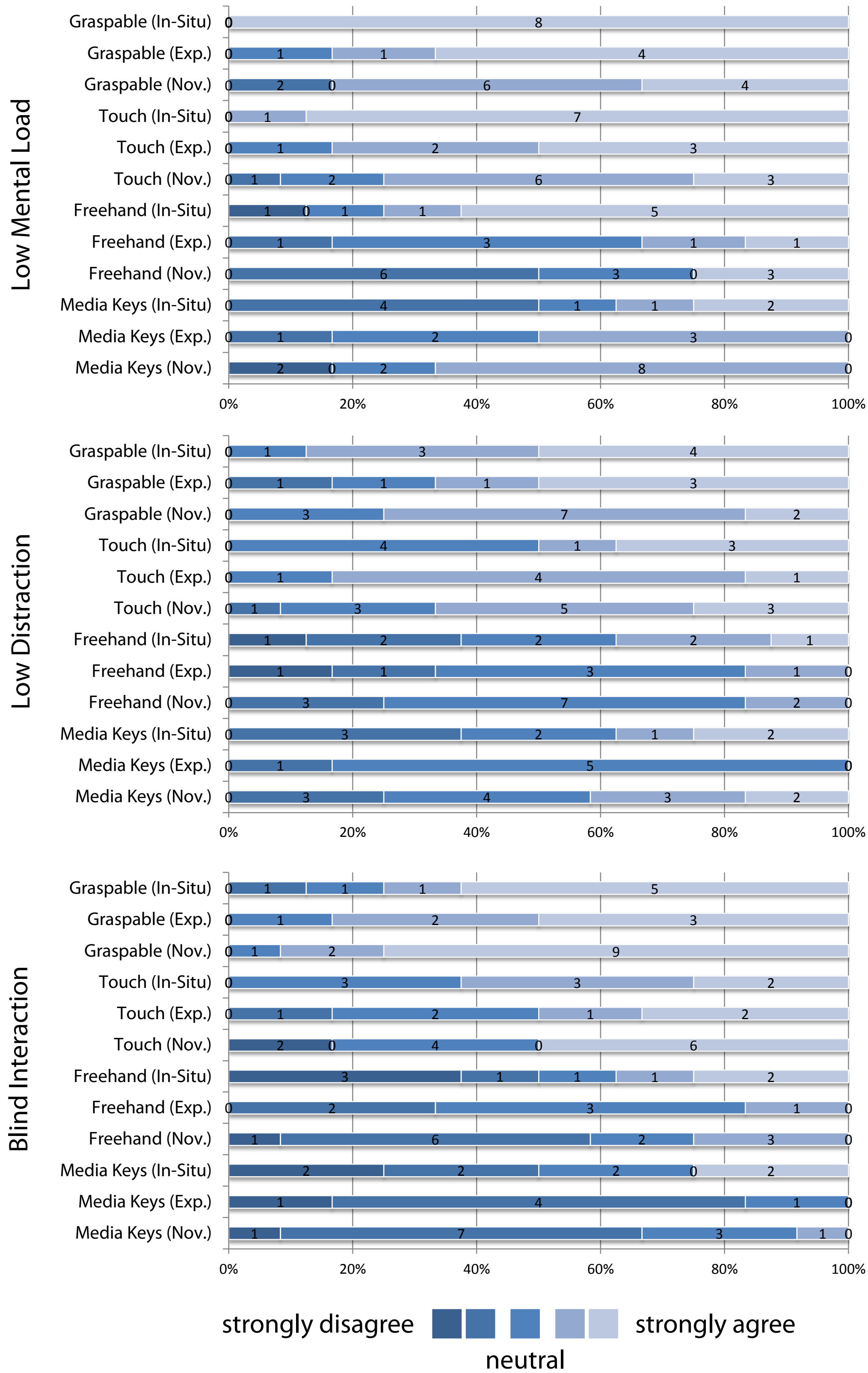

Figure 9.7: Likert scales for *low mental load*, *low distraction* and *blind interaction*.

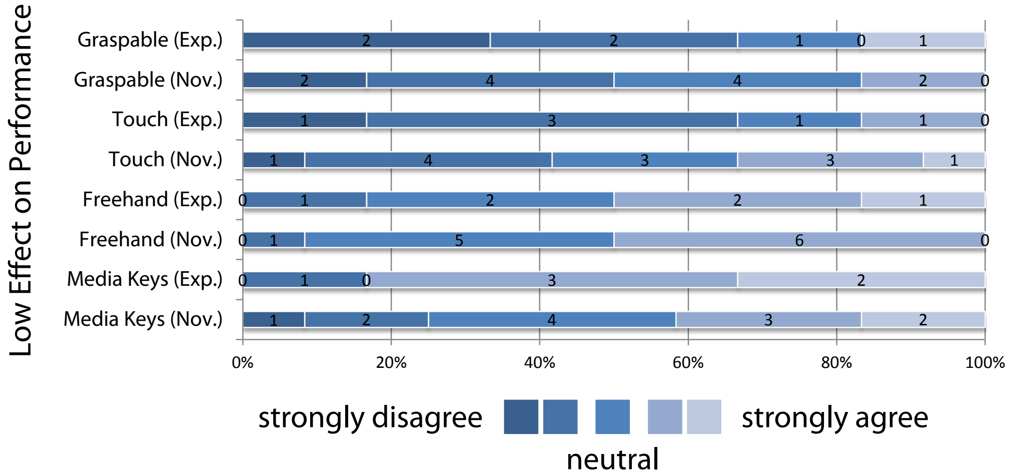

Figure 9.8: Likert scales for *low effect on performance*.

9.3.3 Discussion of Results

We evaluated the Peripheral Music Controller through an in-situ deployment and in the lab with two user groups – experienced participants who took part in the in-situ deployment before and thus already knew the devices and novice users who were not familiar with the devices. To assess the validity of our controlled lab methodology, we compared the results between experienced and novice users as well as the results from the in-situ deployment and the lab study. Table 9.3 gives an overview, which results were collected through which study.

Comparison of Results for Experienced and Novice Users

Of course, during the lab experiment we were not able to push the peripheral devices to the periphery and assess their integration into routines or more generally everyday life. However, by comparing lab results from experienced and novice users we assessed whether previous familiarization would alter the results, thus rendering the lab evaluation invalid. Albeit, we did not find any significant difference for *User Groups*, therefore consider the study methodology valid.

However, for peripheral devices we observed a tendency towards experienced users causing more errors in both tasks. We attribute this to a sloppier interaction style that they adopted during the in-situ deployment (thus indicating that they did not focus very much on the interaction, which is the overall goal of peripheral devices). As this effect appeared for all tested interaction styles, we believe this did not affect the overall comparison.

Comparison of Results from the In-Situ Deployment and the Lab Setting

While designing a lab study for peripheral interaction we never intended to replace in-situ deployments but rather extend the spectrum of potential evaluation methods for peripheral interaction. However, to validate the lab study methodology, we also compared the results from the lab to the results from the in-situ deployment.

Table 9.3 summarizes, which results were gathered by which evaluation. For the in-situ deployment we were not able too measure anything about the primary task's performance, as this would have been to intrusive on the participants' privacy. Moreover we could not measure interruption lags or errors in the peripheral task, as interaction was intrinsically motivated and there was no way for us to assess whether the logged interaction was the intended interaction. Last but not least we also could not asses visual attention towards the peripheral devices during interaction. In contrast we collected subjective experiences through semi-structured interviews.

Through both evaluation methods we found the same usability problems (tracking freehand gestures was not reliable for all gestures and short gestures on the touch device were sometimes wrongfully interpreted as taps), which might also be the cause of the rather high error ratios in the peripheral task for touch and freehand interaction. Overall, the graspable device was the most promising device in both studies.

Nevertheless, we found a contradicting result for mental load. During the lab evaluation mental load for freehand interaction was considered high but mental load for media keys was considered low. During the in-situ deployment ratings were exactly the opposite. One

Table 9.3: Summary of findings comparing results from the in-situ deployment, and the lab experiment with experienced (Exp) and novice (Nov) users. Grey check mark means that the result differed more than one (in terms of the median).

	In-Situ	**Lab (Exp)**	**Lab (Nov)**
Performance Ranking Primary Task		✓	✓
Error Ratio Ranking Primary Task		✓	✓
Interruption Lag Ranking		✓	✓
Error Ranking Peripheral Task		✓	✓
Tracking freehand (pause/play, volume)	✓	✓	✓
Tracking touch (pause/play)	✓	✓	✓
Gaze Ranking Peripheral Task		✓	✓
Subjective Ranking	✓	✓	✓
Learnability, Easiness, Enjoyment	✓	✓	✓
Mental Load	✓ (grey)	✓	✓
Distraction	✓	✓	✓
Gazing	✓	✓	✓
Integration into Daily Life (usage compared to traditional interaction, unexpected usage etc.)	✓		

possible reason might be, that participants were very focused on the peripheral devices during the lab study and thus very aware of their location (while during the in-situ deployment participants sometimes were confused by the location the buttons). Moreover, in the lab we asked for a rather precise interaction to adjust the volume to a medium level, participants in the field were not required to precisely adjust parameters, thus tracking issues with the freehand device might have disrupted the interaction flow more in the lab and thus imposed more mental load.

Finally, we were not able to really assess visual attention during the in-situ deployment. In contrast we could analyze every gaze in the lab and found that participants gazed at the media keys for every single interaction. During the in-situ deployment we only had the focus of the audio player as weak indicator. There we found, that media keys were the device with most interactions without the audio player in focus. We assume that participants trusted media keys most during interaction and thus did not rely on visual additional feedback on screen, however, media keys still were very visual demanding during the interaction in the lab (no interaction without looking at the keyboard). However, subjective ratings on visual attention were in line for both studies – lab and in-situ – as well as for both user groups – experienced and novice. Overall, subjective data was coherent and consistent and thus proved to be a reliable measurement.

9.4 Comparison to Everyday Peripheral Tasks

During the case study and the study for Interaction Styles & Feedback (cf., Chapter 7.2) we collected results about performance and error ratios in the primary task as well as interruption lag and resumption lag. While these numbers can already be used to compare different design ideas, they are rather isolated from any real world context. Thus we selected several everyday peripheral tasks that are often carried out while working at a computer (e.g., drinking coffee) and compared them in terms or the before mentioned measurements with the help of our lab-based evaluation method[3] [104].

Bakker et al. [23] also previously compared their peripheral device FireFlies (cf., Chapter 4.4.1) with typical tasks teachers perform during class. The ranking was based on subjective data. We add on this by providing quantitative data for typical desk-based side activities.

9.4.1 Selecting Everyday Peripheral Tasks

For evaluation we selected six tasks as everyday peripheral side tasks. We tried to pick tasks that are regularly executed and cover a range of task. Table 9.4 gives an overview of all

[3] Chapter 9.4 is based on: Hausen, D., Loehmann, S., and Lehmann, M. Everyday peripheral tasks vs. digital peripheral tasks. In Extended Abstracts on Human Factors in Computing Systems (CHI), ACM, 2014, 6 pages.

Table 9.4: Selection of tested everyday tasks. Depicted senses only refer to senses that are usually also used for a computer-based primary task. Types refer to Jin et al.'s [135] seven types of self-interruption.

Task	Execution	Peripheral Task Type	Interruption Type
Drink	Binary	Bodily	Break, Routine
Food	Binary	Bodily	Break, Routine
Light	Binary	Bodily	Adjustment
Note	Non-Binary	Bodily, Cognitive, Sensorial (Auditory/Visual)	Recollection
TV	Non-Binary	Bodily, Cognitive, Sensorial (Auditory/Visual)	Break
Talk	Non-Binary	Cognitive, Sensorial (Auditory)	Break, Inquiry

tasks and depicts different categories we used to classify the tasks. Execution can either be binary, indicating there is only one possibility to execute (e.g., switching the light on/off or drinking), while the non-binary tasks offer a bigger range of potential executions (e.g., watching TV can be carried out by mainly listening to the TV and just glancing there every now and then, or really attentive watching, additionally, one can only watch or also change channels).

Based on Bakker et al. [22], peripheral everyday tasks can be categorized into three different task types: sensorial, cognitive and bodily (cf., Chapter 4.4). We set out to cover all of these tasks types by our selection of everyday peripheral tasks. Similarly to Bakket et al.'s findings, most of our tasks are bodily involving the arms and hands, however, talking to somebody only involves the cognitive and sensorial capabilities.

The final category is based on Jin et al.'s [135] seven types of self-interruption (cf., Chapter 2.1.2). However, we here only address those types of self-interruptions, which are unrelated to the primary task, as our primary task was an artificial task and thus there were no related tasks. The only exception is inquiry. While our conversation was not related to the primary task, one can easily imagine talking being related to the primary task. Break, routine interactions or adjusting something at one's desk is not considered to be related to the primary task. Recollection is considered to be unrelated to the primary task according to Jin et al., however we believe that taking a note for later recollection could also be related to a primary task.

9.4.2 Procedure of the Lab Evaluation

To gather comparative data we used the lab study methodology as proposed in this chapter. Similar to the case study with the Peripheral Music Controller and the study for Interaction Styles & Feedback we needed to add triggers for the secondary task. To do so we added visual icons on the right side of the primary task, thus close to the visual focus of the participants during the interaction with the primary task. More over in some cases we also added auditory cues (taking a note and having a conversation).

Tasks

The six everyday tasks were integrated as follows:

Drink: We placed a glass with a drink of their choice next to the keyboard before the study and told them to take a sip for every trigger.

Food: Participants chose a chocolate bar before the start of the trial, which was located next to the keyboard. Whenever the trigger for eating was shown they took a bite. Additionally, when the first trigger appeared they also had to unwrap the chocolate bar.

Light: A desk lamp with a flip switch was located at arm's length on the desk. When the first trigger appeared they were asked to switch on the light. For the second trigger they switched the light off and so on.

Note: To take a note, pen and paper were placed next to the keyboard. Next to the icon trigger they were also told (via a recorded voice) what to write down. We used short and simple messages such as writing down an appointment consisting of a name, a day and a time.

TV: A remote control was located next to the keyboard. Upon the first trigger participants were supposed to aim the remote control at the screen and turn on a video, for the second trigger they paused the video and so on. The pause and play button was the same button on the remote control, thus participants only had to remember one button to control the video.

Talk: To mimic a conversation, a short and simple questions (e.g., "how are you?" or "are you still at university?") were asked while also displaying the corresponding icon. Participants then should answer these questions, however, they of course were not obligated to answer truthfully.

Participants

Overall we recruited 18 participants (3 female) ranging in age from 22 to 31 (average age of 25). We asked them if they usually carry out any of the tasks they would be asked to carry out later in the study and found that 17 participants (94%) do drink while working on their computer or take notes. 16 participants (89%) talk to other people while 15 participants (83%) eat at their computer. Additionally 14 participants (78%) watch TV in parallel and 10 (56%) use a desk lamp. Hence, all the tasks that are carried out during the study are carried out regularly by our participants in their daily lives.

Experimental Design and Procedure

We used a Latin square design to counterbalance our independent variable *Task* (Drink, Food, Light, Note, TV, Talk). For each task, every participant got four triggers randomly distributed during one round. However we made sure to space them enough so participants could easily perform the everyday tasks and return to the primary task before another trigger interrupted them.

As dependent variables we counted the overall *number of correctly removed items* in the primary task as well as *errors*. Moreover we calculated the *interruption lag* (from the last click in the primary task till starting the interaction in the secondary task), the *resumption lag* (from the last interaction in the secondary task till the first click in the primary task) and the overall *duration* in the secondary task. To measure the start and end of the interaction with the everyday tasks, we placed a clock (also showing milliseconds) in the video that we recorded during the experiment and later analyzed this data.

Participants first answered an introductory questionnaire. Afterwards they were introduced to the primary tasks and we conducted a baseline measurement (interaction with the primary task without interruption by a secondary task). Afterwards they conducted six rounds, one for each everyday task, where they performed the primary task and the secondary task. The order of the tasks was counterbalanced across all participants. After each round with one everyday task we handed them a questionnaire assessing the secondary tasks as well as a comparative questionnaire at the end of all tasks.

9.4.3 Results of the Lab Evaluation

Similar to the previous lab-based studies we calculated the performance and error ratio for the primary tasks alongside the interruption and resumption lag. Moreover we collected subjective data to assess the perceived difficulty and disruption of the everyday tasks. As we collected this data mainly for comparison to results from lab studies which digital devices we refrained from statistical analysis between the different everyday tasks.

Performance:

We counted the successfully removed items in the primary task while parallel interacting in the secondary tasks. We found that participants performed best (number of removed items in the primary task) while switching the *Light* on and off ($m = 221.3$, $sd = 43.3$) followed by *Talk* ($m = 214.8$, $sd = 35.6$), *Drink* ($m = 204.2$, $sd = 35.5$), *Note* ($m = 203.8$, $sd = 36.1$), *Food* ($m = 188.4$, $sd = 42.1$) and *TV* ($m = 174.6$, $sd = 39.8$).

TV, although the interaction itself (pressing a button on a remote control) was rather short, still performed the least well because some participants completely stopped working on the primary task but instead watched the video, as they later stated they really were curious about it[4]. While participants were eating *Food* the task of taking a bite also did not take up that much time, but chewing still seemed to disrupt them, although hands were already free again to carry out the primary task. In contrast, during the *Talk* many participants kept interacting with the primary task while talking.

Error Ratio

As error ratio in the primary task we calculated the number or errors compared to the overall correct hits. Least errors have been carried out with *Food* ($m = 7.6\%$, $sd = 5.5\%$) followed by *Note* ($m = 7.9\%$, $sd = 4.4\%$), *Drink* ($m = 8.3\%$, $sd = 5.1\%$), *Talk* ($m = 8.9\%$, $sd = 6.1\%$), *TV* ($m = 9.9\%$, $sd = 5.7\%$) and *Light* ($m = 10.4\%$, $sd = 5.7\%$). Thus, with *Light* having the best performance, this high performance also seemed to provoke errors.

For the secondary tasks only three triggers were overlooked by the participants, hence we did not analyze them further.

Interruption and Resumption Lag

We calculated the interruption and resumption lag for all tasks but *Talk*, as participants mostly carried on with the primary task while answering the questions. Thus they never stopped the interaction in the primary task.

Interruption Lag: As interruption lag we calculated the time between the last interaction in the primary task till starting to interact with the secondary task. We found the shortest interruption lag for *Light* ($m = 0.95$s, $sd = 0.63$s) followed by *Food* ($m = 1.07$s, $sd = 0.27$s), *TV* ($m = 1.10$s, $sd = 0.17$s), *Note* ($m = 1.15$s, $sd = 0.35$s) and *Drink* ($m = 1.18$s, $sd = 0.39$s).

Resumption Lag: Similarly, we calculated the resumption lag as time between finishing the interaction in the secondary task and starting again the primary task. Again *Light* ($m = 1.79$s, $sd = 0.85$s) caused the least break followed by *Drink* ($m = 1.81$s, $sd = 0.52$s), *Note* ($m = 2.25$s, $sd = 0.68$s), *Food* ($m = 2.64$s, $sd = 0.82$s) and *TV* ($m = 3.04$s, $sd = 1.35$s). Similar to the results from *Interaction Styles & Feedback* we found the resumption lag being longer then the interruption lag.

Duration: Additionally we calculated how long the interaction with the secondary task took. We found the shortest interaction time for *Light* ($m = 1.38$s, $sd = 0.36$s) followed by *Talk* ($m = 2.58$s, $sd = 1.64$s), *TV* ($m = 3.22$s, $sd = 1.38$s), *Drink* ($m = 4.84$s, $sd = 0.58$s), *Food* ($m = 5.42$s, $sd = 1.51$s) and *Note* ($m = 5.85$s, $sd = 1.57$s).
When adding the interruption and resumption lag to the duration, thus calculating the overall duration a participant on average did not attend to the primary task the ranking only changes for *Light* and *Talk* as we could not detect any interruption or resumption lag for

[4] They saw a documentation on the "Miniatur Wunderland Hamburg" (cf., http://www.miniatur-wunderland.de – Last Accessed: 06.08.2013)

Talk. Thus, *Talk* (m = 2.58s, sd = 1.64s) caused the shortest overall duration followed by *Light* (m = 4.15s, sd = 1.27s), *TV* (m = 7.49s, sd = 2.60s), *Drink* (m = 7.89s, sd = 1.11s), *Food* (m = 9.13s, sd = 1.85s) and *Note* (m = 9.25s, sd = 1.87s).

Subjective Data

Generally all tasks have been considered to be **fairly easy** (all $median \geq 4$). Based on a Condorcet ranking, taking a *Note* was considered to be the most **difficult** task followed by *Talk*, *TV*, *Food*, *Light* and *Drink*. In contrast, **disruption** was considered to by highest for *TV* followed by *Note*, *Talk*, *Food*, *Light* and finally *Drink*. In line with this are the subjective ratings whether participants felt they needed to **concentrate** on the everyday task: *TV*, *Note*, *Talk* and *Food* required a bit more concentration (all $median = 3$) compared to *Light* and *Drink* (both $median = 2$).

Overall, although all our participants regularly carry out many of the tasks that we presented in the study while working on a computer, in a everyday situation ratings probably would still be a bit better. The position of the desk light for example would be more familiar. The same is true for the TV's remote control, which in the study was unfamiliar to the participants. On the other hand conversations might be more complicated than the one we simulated and a note might also be longer. Nevertheless, we believe the collected data is beneficial to get a first glimpse on the effects of everyday tasks on computer-based work and offers some kind of comparison for results with digital peripheral task.

9.4.4 Comparison of Results

We were motivated to carry out the controlled lab evaluation method with everyday tasks to have a basis for comparison with digital peripheral tasks. Here we first briefly compare the results of the everyday tasks and afterwards we also compare the everyday task results to the results of the other studies.

Comparison of Everyday Task

Figure 9.9 summarizes the results (performance, duration and error ratio). One interesting finding is that one cannot deduce from the performance the duration of the interaction with the secondary everyday task. For instance taking a note takes most time but does not cause the biggest loss of performance. We believe that this is due to internal cognitive processes that are different for each task. Thus, even if the (manual) interaction with the everyday task is already finished, participants still seem to be disrupted (more) by some tasks, thus leading to more degradation in the overall performance. The most obvious example is turning on the TV (which is a rather short interaction itself). However, having the TV switched on during the interaction lead to the worst performance. This observation most likely holds also true for digital peripheral tasks as we for example also observed for StaTube's timer

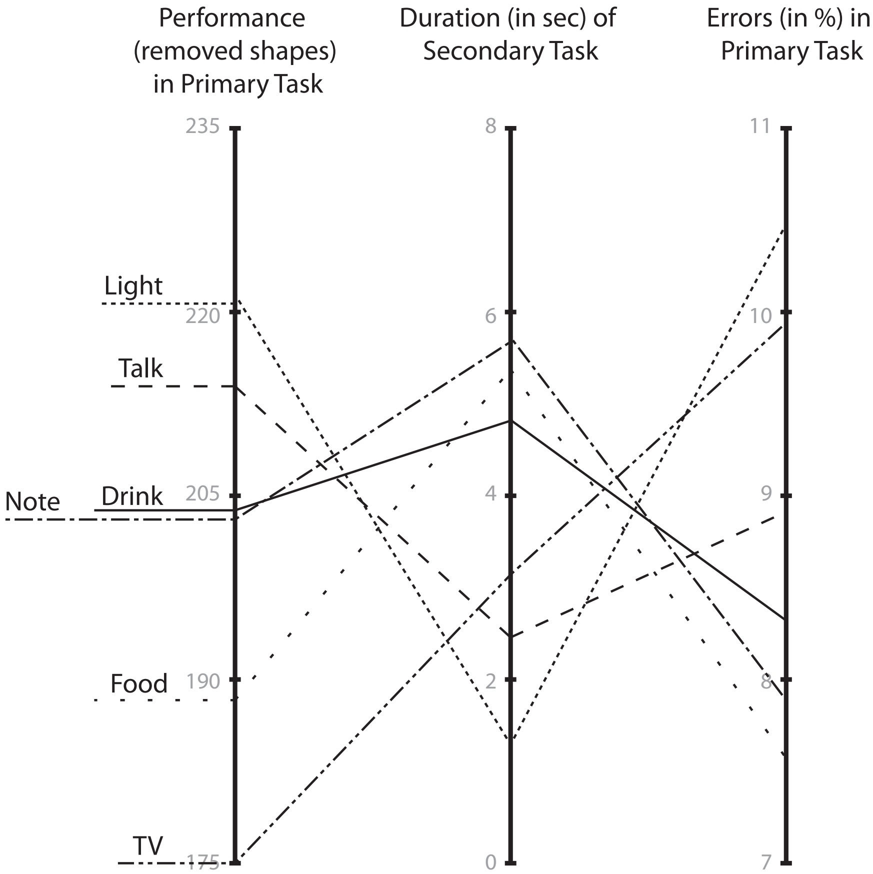

Figure 9.9: Results for all everyday tasks. While axes do differ, the interesting finding visible is that lines do not even roughly run parallel indicating that the performance while interacting with a secondary peripheral everyday task does not give insights on the duration or the errors caused by this task.

(cf., Chapter 6.1) that the interaction itself was simple but the cognitive processes behind (considering the expected duration of an absence) was too demanding to become peripheral.

Comparison to Other Studies

Apart from the everyday tasks we also evaluated *Interaction Styles & Feedback* (see Chapter 7.2) and the Peripheral Music Controller (in the case study, see Chapter 9.3) with the help of the lab evaluation methodology. Thus Table 9.5 summarizes and ranks some exemplary results (performance (here for comparison per minute), error ratio and interruption lag) for all of these three studies.

When looking at Table 9.5 it is obvious that everyday tasks mostly rank in the top positions. This indicates that they overall impose less disruption on the participants than the evaluated digital peripheral tasks. However, the everyday tasks were very common and thus trained

Table 9.5: Comparison of Everyday Tasks (black), Interaction Styles & Feedback (green/**) and Peripheral Music Controller (case study) (blue/*). (To increase readability we here only state the means, omitting standard deviations.)

Performance (per min)		Error Ratio		Interruption Lag	
73.8	Light	7.6%	Food	—	Talk
71.6	Talk	7.9%	Note	0.95s	Light
68.1	Drink	8.3%	Drink	1.07s	Food
67.3	Note	8.9%	Talk	1.10s	TV
67.2	Graspable (Nov)*	9.9%	TV	1.18s	Drink
64.5	Touch (Nov)*	10.4%	Light	1.15s	Note
64.0	Graspable (Exp)*	11.0%	Touch (Nov)*	1.66s	Graspable (Exp)*
62.8	Food	11.1%	Graspable (Nov)*	1.74s	Touch (Exp)*
61.0	Freehand**	11.2%	Graspable (Exp)*	1.97s	Graspable (Nov)*
60.8	Media Keys (Nov)*	11.2%	Freehand**	2.02s	Media Keys (Exp)*
59.8	Touch (Exp)*	11.9%	Media Keys (Nov)*	2.04s	Touch (Nov)*
59.1	Touch**	12.0%	Touch**	2.06s	Touch**
58.2	TV	12.2%	Freehand (Nov)*	2.09s	Media Keys (Nov)*
58.1	Freehand (Nov)*	12.4%	Freehand (Exp)*	2.31s	Freehand (Nov)*
55.0	Media Keys (Exp)*	13.0%	Media Keys (Exp)*	2.32s	Freehand**
53.4	Freehand (Exp)*	14.4%	Touch (Exp)*	2.58s	Freehand (Exp)*
52.4	Graspable**	14.9%	Graspable**	2.73s	Graspable**

way better than any digital peripheral task. Moreover, when having a closer look at the numbers, numbers between everyday tasks and digital peripheral tasks do not differ that much. Thus we believe that, if integrated into daily life and thus being properly habituated and trained, our digital peripheral tasks could score equally well as the everyday tasks.

9.5 Summarizing Evaluation for Peripheral Interaction

We observed that the iterative design process is not exploited for peripheral interaction but mostly in-situ deployments at the end of the design of a prototype are conducted. To enrich the design process for peripheral interaction, this chapter summarized related work on evaluation in the field of peripheral interaction but also related fields such as ambient information, multitasking and interruption management. Based on the literature review we designed a lab-based evaluation methodology to offer early testing of peripheral designs at least for desk-based use cases. We were able to validate the methodology by comparing results for the Peripheral Music Controller based on this lab-methodology and the previously conducted in-situ deployment (cf., Chapter 7.1). To better estimate results derived by this lab-based approach, we also evaluated six everyday tasks, for instance drinking or taking a note, with this lab-based approach and thus offered numbers for performance, errors and interruption as well as resumption lag for comparison.

From these explorations of evaluation methods we believe that the design process for peripheral interaction can be enriched especially for early design phases to uncover usability issues of peripheral devices before deploying them for an extended period of time. Consequently, we by far do not want to render in-situ deployments unnecessary but believe in coupling both approaches to design successful devices for peripheral interaction. More implications that we can derive from our experience with evaluating peripheral interaction are listed in Chapter 10.7.

III

Reflecting on Peripheral Interaction

Chapter 10

Design Implications for Peripheral Interaction

Synopsis

Based on the previous projects we here look at the big picture. Applying peripheral interaction to digital devices offers several benefits. People can more easily access functionality as peripheral interaction can be used as a shortcut. But not only existing functionality can be accessed, new functionality can also be added by peripheral devices, for instance because they are decoupled from standard input devices. However, for successful adoption, peripheral interaction has to be learned and more importantly habituated, which also includes to break loose of old habits and replace them with peripheral interaction, thereby reducing visual and mental attention for side tasks. Through all our projects we showed, that not only tangible or graspable devices – as explored by related work – can be successfully deployed for peripheral interaction but also touch and freehand gestures can be used to offer interaction in the attentional and visual periphery. To assure people in their interaction, different levels of feedback – inherent, functional and additional – can be used to enrich peripheral interaction. Moreover, interaction should be coarse to be executable in the periphery. This also includes that interaction is not limited to the dominant hand, but also the non-dominant hand can be used to carry out input. Finally, to build successful systems, an iterative design process and especially evaluation is important during all stages of the development.

In the previous chapters we presented six different prototypes – StaTube, Appointment Projection, Peripheral Music Controller, Interaction Styles & Feedback as well as the Unadorned Desk 2D and 3D. All these projects examined different aspects in the scope of peripheral interaction. Starting off with basic explorations relying on one interaction style we followed up with comparative studies and finally examined the specific aspects of interaction based on spatial memory. All projects target desk-based scenarios, thus imagining a primary task on a desktop computer. We derived lessons learned for each of these projects. The following chapter summarizes these findings and puts them in a wider context showing a bigger picture. These here listed implications shall offer guidance for designing and building interactive devices for peripheral interaction.

10.1 Benefits

Peripheral interaction is motivated by the observation of everyday actions with our physical world, such as drinking a cup of tea or tying our shoe laces, which we easily carry out without focusing on them. With more and more digital devices entering our daily lives, the number of tasks that we carry out with these digital devices also increases. Thus, the overall goal of peripheral interaction is to reduce the negative effects of interruptions by side tasks while working with digital devices. Currently, most tasks require to switch windows and hence the current focus, which can be improved through peripheral interaction by several means. However, benefits of peripheral interaction are not only limited to the reduction of consequences induced by interruptions.

10.1.1 Shortcut and Simplification

Peripheral devices can *offer shortcuts* to certain commands, functionality or information. Participants stated that interaction was more comfortable, easier and faster than the interaction with the traditional GUI, which usually required precise clicks and window switches (cf., StaTube). In contrast, when using the peripheral device, the traditional GUI was often minimized or hidden by other applications, thus not visible during interaction (cf., Peripheral Music Controller). Of course, this not only fosters tasks that are otherwise ignored but can also simplify tasks that are mandatory to take care of.

Generally we observed that the *interaction barrier was lowered* by peripheral devices. We noticed that participants interacted way more with the Music Controller (cf., Chapter 7.1) while being equipped with one of the peripheral devices than when they only had media keys available. Indeed this could partially be because of the novelty effect, however, we observed this behavior during an eight week deployment, thus participants by then should have mostly overcome the novelty effect.

10.1.2 Extending Functionality

Apart from offering a shortcut to some functionality, peripheral devices can also *extend the functionality* of applications. For instance when implementing StaTube (cf., Chapter 6.1) we extended the number of states provided by the instant messaging client (directly displayed on the peripheral device and included as mood messages in the instant messaging client). While of course the additional states could also have been typed into the mood message before that would have been even more cumbersome than changing the regular states, which was already neglected before the introduction of StaTube.

Moreover, *information capacity can be increased* while not increasing salience and thus disruption. For the Appointment Projection (cf., Chapter 6.2) we opted for an ambient calendar representation, which has been done by several other research projects before (e.g., [67, 194, 266]). However, ambient information systems are usually abstract and cannot provide rich information but merely an overview. By adding peripheral interaction to our ambient projection we were able to keep the system in the attentional periphery but on demand offer details about appointments without having to completely shift from the primary task (e.g., by switching windows). Thus peripheral interaction can be used to keep information available but still make use of ambient information and thereby lowering disruption.

10.1.3 Decoupled Devices

All peripheral devices that we built and tested were separate devices decoupled from standard computer peripherals such as keyboards. We thereby discovered *new usage scenarios* that we did not expect while building the devices. For instance, participants started to carry around the touch devices for the Peripheral Music Controller (cf., Chapter 7.1) as it was not tied to a cable and used it as remote control. Moreover, distinct devices also act as a *reminder* to carry out a task (cf., StaTube). This is especially helpful for unannounced tasks, thus tasks that need to be initiated by the user and rely on prospective memory [255]. Finally having a dedicated and decoupled device also offers *access to functionality* while the computer might already be locked. While of course this might raise security issues, participants really liked that about StaTube (cf., Chapter 6.1) because this enabled them to integrate into their workflow changing the state to "away" (e.g., locking computer, grasping keys, turning StaTube and finally locking the door) while leaving.

However, having a separate and thus extra device on the table was also considered to be inconvenient by some participants. For future implementations we can imagine to *integrate tracking* into current hardware. For instance integrated web cams can be used for vision-based gesture tracking, or track pads can also interpret peripheral touch interaction. Nevertheless this imposes mode switches for these devices, for instance indicating that one wants to use the touch pad for peripheral input in contrast to regular input. This not only adds another interaction step, one should also make sure not to rely on keyboard shortcuts [147] or extra keys on the keyboard for mode switches, as we saw in the study for the Peripheral

Music Controller (cf., Chapter 7.1) that media keys were far less successful than our other devices. We believe with future technology being more miniaturized, tracking devices can easily be integrated into current hardware, or physical artifacts such as desks, furniture in general or even clothes and thus not being perceived as separate devices.

10.1.4 Interplay with other Applications

Moving tasks from the screen based environment to the periphery includes *freeing screen space* for other applications and other tasks (cf., Unadorned Desk). Moreover, tasks carried out in the periphery can also enrich other applications. For instance, now up to date state *information can be used for other applications*, such as postponing deferrable notification if a user indicates being busy. Thus not only the interaction itself lowers the effect of interruptions, but further improvements can be made according to the provided data.

10.2 Learnability and Habituation

Introducing new interaction styles takes some time. For peripheral interaction we observed that the learning of the actual interaction is pretty short, however to be successfully integrated into daily life and everyday routines it takes a considerable amount of time.

10.2.1 Learning of the Interaction

Usually interaction used for peripheral interaction is easy and straightforward, such as turning (e.g., StaTube, PolyTags [189]) or pressing (e.g., FireFlies [23, 25], Notelet [26]) devices or using wiping and flick gestures (e.g., Appointment Projection, Peripheral Music Controller) or taps and swipes on touch surfaces (e.g., Peripheral Music Controller, Interaction Styles & Feedback). These actions usually do not have to be learned – especially as most of the time coarse interaction is enough. Only memorizing the mapping between a simple interaction and the associated command takes some time. However, by establishing a good mapping, for instance inspired by the interaction with the physical world, memorization should be simplified (e.g., wiping towards oneself to acquire details about an upcoming appointment, like fetching something on the desk, cf., Appointment Projection). Nevertheless, if tasks get a bit more complex, including more commands (cf., the Unadorned Desk), learning all possible interactions and their mappings might take a bit more time.

When looking at examples of peripheral interaction in our physical lives, one also notices that for some tasks a bigger amount of time is needed to learn the interaction and move it to the background and thus periphery. For instance, hardly anybody will remember it, but learning to walk was once hard and took time to really accomplish it properly. However, today we do not think about walking and carry out many other things in parallel. Another example, which one might still remember is learning to type. To be able to blindly type and not consciously think about the finger movement took a lot of time, however, with enough training, typing without thinking about the hand and finger movement can be easily performed. We thus believe that a certain amount of learning time can be accepted, especially for tasks that afterwards are performed regularly in the periphery.

10.2.2 Breaking Habits to Achieve Habituation

In contrast to the interaction itself, we observed that shifting the interaction to the periphery really needs to be learned. Generally, people are not used to interact in the periphery with digital devices, although this is very common in physical life. The biggest issue is breaking habits that have been established over the years and which are part of the current routine (e.g., pressing alt+tab to switch windows and get to the audio player to change a song, cf., Peripheral Music Controller). Similar findings have been reported by Bakker et al. stating "that existing habits may need to be unlearned" [19] to successfully integrate peripheral interaction devices. Researchers in different contexts also report that "habitual patterns dominate" [147] and it is very unlikely for people "to switch to new strategies" [147]. Thus, although adopting peripheral interaction in the long run is usually very beneficial for users, in the beginning one imposes "work" on them, to actually change their habits. During our studies we also observed that two weeks are often not enough to achieve this change of habits. Participants who took part in the Peripheral Music Controller (cf., Chapter 7.1) study told us that even though they switched devices every two weeks they felt like the process of getting used to the periphery and adapting peripheral interaction in general still progressed over the complete eight weeks independent of the device.

10.3 Visual and Mental Attention

As we established in the previous section (cf., Chapter 10.2) habituation is an important aspect for peripheral interaction to actually shift to the periphery and thus only causing minimal mental and visual load. However, measuring attention is not a trivial task. A lab setting offers the possibility of close observation, but the situation is artificial thus the participants might overly focus on their current task. In contrast, when evaluating in the field, observation is limited and one has to rely on weak indicators such as the input focus of applications on screen while interacting. This gives first insights whether participants felt the need to look at the GUI for visual feedback of the changes, however, it does not offer any knowledge whether participants looked at the device during interaction. (A more detailed discussion on advantages and disadvantages of lab experiments and in-situ deployments can be found in Chapter 10.7.) Independent of issues concerning the evaluation of visual and mental attention, this section summarizes findings derived from our projects.

10.3.1 Visual Attention

If a peripheral task draws visual attention towards itself, people cannot in parallel visually attend to the primary task (structural interference [141] or intra-model time sharing [254], cf., Chapter 2.1.1). Especially for computer-based scenarios this usually involves a disruption of the primary task, as computer-based work usually heavily relies on the computer's display and thus the visual channel. However, the visual channel is not only relevant for computer-based tasks but most (primary) tasks require us to look at them. Hence, interaction should not be designed in a way that requires visual attention to be executable (e.g., precise pointing at certain locations on a smooth surface without any haptic cues). Kahneman [141] calls this type of looking *task-relevant looking*. However, there is a second category of looking at a device, which is called *looking accompanied by internal processing* [141]. Thus, participants are not really looking at the device because they need to look to carry out the interaction, but instead their visual attention gives information about their thoughts. Hence, while cogitating about the interaction they often also automatically look at the location of the interaction (cf., Chapter 2.1.1).

For all projects we observed (either directly through lab experiments or through subjective feedback during interviews) that participants in the beginning were drawn to look at the devices during interaction. However, we found that after some time (cf., Chapter 10.2) and especially when other visual cues captured their attention (e.g., another task or the feedback window in the Unadorned Desk 2D study), looking at the peripheral device during interaction decreased. Thus we believe that the observed looking at the devices was in fact only *looking accompanied by internal processing*. However, sometimes users also briefly glanced at devices to locate them. These mostly were not very focused glances but rather based on *ambient vision* [254] (cf., quick glancing while grasping for a cup of tea while reading a book). We further found that physicality of the input device or interaction style influences visual attention (cf., [76]). As physicality decreased from graspable to touch and finally freehand interaction, we could observe an increase in visual attention (cf., Peripheral Music Controller). These issues could be reduced by offering bigger interaction areas (cf., touch and freehand tracking area for Interaction Styles & Feedback) and thus coarser interaction. Nevertheless to minimize false positives of gesture tracking, real life scenarios might limit the size of the tracking area. On the other hand, especially if tracking is positioned on a fixed location habituation again will help to reduced glances for locating devices.

To sum up, in our experiments participants in the beginning always felt the need to look at their hands or the device during interaction. But this behavior decreased through habituation and only rarely showed later as *looking accompanied by internal processes* or *ambient vision* to located the device. We do not consider this to contradict successful peripheral interaction, as it only shows rarely and both might decrease even further by carrying out a task in parallel (which was missing for the Unadorned Desk studies) and increased habituation.

10.3.2 Mental Attention

We believe that some mental attention is needed to carry out peripheral interactions, at least to form the conscious decision to interact (as we aim at explicit interaction with all our prototypes). However, during the interaction itself mental load should be low to minimize negative effects of disruptions by secondary tasks (e.g., delay between both tasks [8], duplicated work [255], increased execution time [17]). Participants stated that they perceived only low mental load during the execution of nearly all investigated peripheral tasks. This finding based on subjective data is backed up by a higher interaction frequency while in parallel starting to neglect GUI and mouse for the task (cf., StaTube, Peripheral Music Controller). Thus we believe participants enjoyed peripheral interaction and were less bothered by it than by the graphical user interface for the same task.

Of course one can argue whether an *increased interaction frequency* is beneficial as any type of parallel task will have an effect on the primary task, even if only a marginal one. We believe that this is a question of the current scenario and secondary task. If the secondary task is important to be carried out, but it is often neglected because it is considered to be too cumbersome, it indeed is beneficial if more interaction now is carried out. For the use case of the Appointment Projection (cf., Chapter 6.2) we even found that we imposed less distraction although we added an interaction step to the overall work flow. While traditional reminders show all relevant information about an appointment immediately, they were more disruptive than only calmly reminding about the next appointment and asking for an explicit (but peripheral) interaction to acquire more details. We believe this is because traditional reminders appear at potentially unsuitable moments while users of the Appointment Projection could decide on their own when to acquire details and thus might have made use of sub task boundaries or in general used moments where they felt comfortable disrupting their primary task [16]. Thus, we conclude that the number of single interactions is no suitable measurement to assess how disruptive and hence mentally demanding a task might be.

We moreover calculated the *interruption and resumption lag* for the lab based experiments and found that the interruption lag was shorter than the resumption lag (cf., Interaction Styles & Feedback). During the interruption lag people try to convey the state of the primary task for easier resumption later. Additionally, users mentally prepare for the switch to the secondary task. Having a short interruption lag thus might indicate that only little mental preparation is needed to attend to the secondary task supported by a peripheral device. Moreover this might also include that rehearsal of the primary task is not as important and thus can be speed up, because the peripheral interaction is not perceived as real focus switch. We also found similar results for the study with everyday tasks (cf., Chapter 9.4). As we selected everyday tasks that can be performed in the periphery in daily life, we believe this also indicates that our digital tasks and respective devices indeed could shift to the periphery.

Finally we also found that not only the interaction itself needs to be simple to be only minimal mentally demanding, but the *associated task* needs to be straightforward (in terms of possible habituation), too. When evaluating StaTube (cf., Chapter 6.1) we found that the new states were well adopted, however the timer was not. Pressing down the upmost level most likely was not a more complex interaction than turning the upmost level, but while people seem to be generally aware of their current state (e.g., just leaving for lunch) it is much harder to assess how long an absence will last (cf., dividing attention is harder at "high levels of effort" [141]). Thus, it was not the interaction that kept people from using this feature but the cognitive process that was imposed on them by deciding which parameters to set this feature to. Hence both – the task itself and the interaction – need to be easy (while easiness has to be understood in terms of training and skill as discussed in Chapter 2.1.3) to only cause minimal mental load and thus move to the periphery.

10.4 Interaction Styles

In this thesis we explored three different manual interaction styles for peripheral interaction: graspable (StaTube, Peripheral Music Controller, Interaction Styles & Feedback), touch (Peripheral Music Controller, Interaction Styles & Feedback, Unadorned Desk 2D) and freehand (Appointment Projection, Peripheral Music Controller, Interaction Styles & Feedback, Unadorned Desk 3D) interaction. Overall we found that all interaction styles are generally fit for peripheral interaction and participants preferred peripheral interaction, independent of the interaction style, over traditional GUI and mouse interaction during all our deployments.

While we can report subjective preferences concerning the interaction styles for each comparative study, we are cautious to award one interaction style as "winner". While the graspable device was the most liked device during the evaluation of the Peripheral Music Controller (cf., Chapter 7.1), it was the least liked device for Interaction Styles & Feedback (cf., Chapter 7.2). These differences most likely can be attributed to implementational issues, thus the graspable device being the most reliable device for the Music Controller, however touch and freehand interaction were more reliable for Interaction Styles & Feedback. Moreover, both studies only explored a very limited range of interaction possibilities for each interaction style (e.g., for graspable interaction only a knob-based design and a tiltable device were used in these two studies). It is impossible in the scope of this thesis (and most likely also in general) to compare all possible manifestations of these interaction styles. Thus this thesis offers some probes into the design space. It is merely a question of use case and scenario, which interaction style to finally pick for a project, as all three interaction styles come with several advantages and disadvantages. However, as expected, manual interaction styles are indeed very feasible for peripheral interaction, as motor tasks facilitate habituation [255].

10.4.1 Graspable Interaction

Targeting always desk- and computer-based scenarios, graspable devices felt rather familiar to our participants. As they were all used to move one hand between keyboard and mouse, reaching for a graspable device did feel rather natural to our participants, thus getting used to graspable interaction was easier than for instance to freehand gestures. Concerning the results of related work, which exclusively rely on tangible or graspable devices [23, 25, 26, 69, 70, 189], we for sure can conclude, that graspable (or tangible) interaction is one suitable interaction style for peripheral interaction.

We found the physicality of graspable devices to be very beneficial, as it offers haptic inherent feedback (cf., Chapter 10.5). In contrast to for instance freehand interaction, where participants do not have immediate feedback whether they performed their gesture in range of the tracking device, graspable interaction ensures participants that their input was recognized by the system. However, grasping the device to some extent is a precise interaction while for touch and freehand interaction, tracking areas can be designed to be bigger and thus offering less precise placement of the hand during interaction and thus coarser interaction. In line with this, based on subjective data, graspable devices were harder to be operated with the non-dominant hand than with the dominant hand (cf., Chapter 10.6).

With graspable interaction offering a huge variety of manifestations, it is important to assess for every graspable device, whether the design works. Parameters to check are the possibility to interact eyes-free, thus minimizing visual attention and making commands haptically distinguishable (e.g., not using several equally shaped objects for different commands).

10.4.2 Touch Interaction

We investigated two types of touch (cf., Chapter 3.2): *continuous* (Peripheral Music Controller, Interaction Styles & Feedback) and *discrete* touch input (Unadorned Desk 2D).

Continuous Touch

Continuous touch input such as swipes are beneficial because they do not require to precisely locate a touch point but can be executed anywhere on the touch sensitive area. However we found that the *size of the interaction area* influences the success. For the Peripheral Music Controller (cf., Chapter 7.1) we used the touch sensitive surface of a mobile device (8 $\times$ 4.8 cm) while we used a larger area on a touch sensitive tabletop (32 $\times$ 23 cm) for Interaction Styles & Feedback (cf., Chapter 7). Touch was more successful for the later project as participants needed to be less precise to locate the tracking area. However, for real life deployments – which we did not investigate for Interaction Styles & Feedback – one needs to find a suitable trade-off between a comfortable sized tracking area and a tracking area, which is small enough to not too easily trigger commands by regular movement on the desk, which is not intended as input. Moreover we found that the number of fingers used for input is irrelevant to users (which is in line with findings by Wobbrock et al. [260]). Offering the possibility to carry out continuous input with a varying number of fingers further supports coarse interaction as users do not need to pay attention on the number of fingers that touch the tracking surface. Nevertheless, if more commands need to be included in a device, the number of commands can be potentially increased by assigning gestures to commands depending on the number of employed fingers.

Discrete Touch

We investigated discrete touch based on spatial memory – thus interacting by touching a distinct location – with the Unadorned Desk 2D (cf., Chapter 8.1). Generally we found that spatial memory can be successfully used to retrieve content in off-screen space, to some extent even without any additional or functional feedback (cf., Chapter 10.5). Two parameters are crucial for successful touching of locations: virtual *item size* (which also influences the number of potential items on a touch surface) and *location of items*. Through experimentation we found that items with a radius of 85mm worked very well for our setup even without any additional feedback (if generally the location was remembered) or landmarks on the desk. However, study results also indicate that picking suitable locations aids recall of items. Suitable locations are locations rather close to the keyboard (cf., Magic Desk [31]) and based on landmarks such as the desks corners or physical items stored on a desk or the touch sensitive surface. Moreover grid based layouts help users to successfully retrieve the correct location of an item. However, we did not investigate how to distinguish intentional touches from regular movement at a desk. For successful real world deployment this would be essential. Nevertheless, based on findings from the Unadorned Desk 3D, we assume that dwell time (thus touching a location for a predefined time frame such as one second) or small finger movements during touch (e.g., spreading a thumb) can be successfully applied.

10.4.3 Freehand Interaction

We limited the exploration to mimetic, deictic and referential gestures (cf., Chapter 3.3). Compared to the previous interaction styles – graspable and touch interaction – we found that familiarization was a bit slower. This is not necessarily due to freehand gestures being more complex but because freehand gestures are not yet as well-known as using a device that can be grasped (e.g., a mouse, which is by definition not a graspable device, however physical and manual interaction is somewhat similar for participants as they move their hand from the keyboard and grasp something different) or interacting via touch (cf., smart phones and tablet computers). Freehand interaction was described as "magical" thus drawing attention towards itself not because it is hard to use, but because it is fascinating. However, this contradicts the peripheral nature that we want to achieve. Nevertheless, firstly our participants got used to freehand interaction after some time and secondly it is likely that freehand interaction will become more common in the near future as Microsoft Kinect already introduced it to the domain of gaming, and new tracking technology such as Leap Motion[1] might open up new application fields. Additionally, most problems that arose during the studies can be attributed to tracking issues, which were more severe than for graspable and touch interaction, but most likely will not be such a big issue in the future. Moreover, fatigue of the arms and hands, which is often stated to be a limiting factor for freehand interaction, is not expected to be a big issue for peripheral interaction, as peripheral interaction is intended for occasional and

[1] HP released the first laptop with integrated Leap Motion in October 2013: http://www8.hp.com/us/en/ads/new-products/envy-17-leap-motion.html (Last Accessed: 14.10.2013)

short side activities in contrast to constant interaction. Thus, arms do not need to be held in midair for longer periods of time.

Overall we investigated freehand gestures in two contexts: *location independent* (Appointment Projection, the Peripheral Music Controller, Interaction Styles & Feedback) and *location dependent* (Unadorned Desk 3D) gestures.

Location Independent Gestures

Location independent gestures are still tied to the location of the freehand tracking device, however, as long as performed inside of the tracking area the precise location does not encode any meaning. Typical location independent gestures that we also used are wiping or flick gestures. Similar to touch input, the size of the tracking area influences how coarse the positioning of the hand and thus the overall process of gesturing can be performed. For the Peripheral Music Controller (cf., Chapter 7.1) we used a device, which tracked a volume with a height of 7.5 cm and a width and depth of 10 cm. Correctly positioning a hand in there was sometimes considered to be difficult. For Interaction Styles & Feedback (cf., Chapter 7.2) we used a much bigger tracking area (32×23 cm and depth of about 5 cm), which was much easier to be located. However, again similar to touch, the tracking area needs to be of a reasonable size, thus easy to locate but hard to accidentally perform interactions just by regular movements of the arms while interacting with the physical world. Finding the best size still is future work, but most likely will also depend on the scenario in which freehand gestures are applied. Moreover, for location independent gestures we observed that positioning the hand during the preparation phase (cf., [71]) was wrongfully interpreted as gesture. This is a well-known issue for freehand gestures, which also needs to be overcome for peripheral interaction relying on freehand interaction.

Location Dependent Gestures

Location dependent gestures rely on the spatial location of a gesture being performed, thus the same gesture is connected to different commands when performed at different locations. With the Unadorned Desk 3D we found that more steady gestures (such as Dwell Time or small finger movements for instance only moving the Thumb) performed better. We assume this is because the perceived tracking location is always visible and best resembles the actual tracked location (the finger tips). Moreover we believe that gestures with less complex finger or hand movements impose less cognitive load although Dwell Time – holding the hand steady for a predefined amount of time – introduces waiting time. However, participants were not bothered by this waiting time. Through experiments we found that items (e.g., associated commands) with a radius of 80mm (being in 3D we imagine items to be spheres) work reasonably well, however for gesture that performed best (Dwell Time) the item's radius could be reduced to 50mm. Similar to touch we found no difference for the interaction with the dominant or non-dominant hand (cf., Chapter 10.6), however the location again influences retrievals. Grid-based arrangements as well as landmarks in the interaction volume help. Additionally participants performed better for items located close to the bottom plane of the interaction volume. Thus we would advise application designers to use the bottom plane and only rely on the vertical axis for stacking semantically related items.

10.5 Feedback

We distinguish three different types of feedback [253]: inherent, functional and additional.

10.5.1 Inherent Feedback

Obviously, all prototypes relying on manual interaction include inherent feedback, thus feedback provided by the movement of our muscles. Some of our prototypes (Unadorned Desk 2D/3D and Interaction Styles & Feedback in the no-feedback conditions) solely relied on that. We found that most interactions in these studies (except for a higher number of items with the Unadorned Desk) were equally well performed (in terms of quantitatively measurable data) without feedback than with feedback. However, participants often felt unsure whether their interaction was successfully tracked and executed by the system. Moreover we observed that inherent feedback especially was problematic for interactions that did not offer any physical contact to a device, namely freehand gestures, as freehand interaction lacks exteroception (perception of surfaces, cf., Chapter 2.2). Participants then did not have any clue if they were at all inside the tracking area during execution of the gestures.

10.5.2 Functional Feedback

In contrast, when having a use case, which also provides functional feedback, such as the music starting and playing for the Peripheral Music Controller (cf., Chapter 7.1), participants felt at ease during interaction although no further additional feedback was available. Functional feedback thus is very powerful for peripheral interaction. There is no need to add more visual or auditory clues, which might again cost some mental resources to interpret, however users are still aware of the results of their interactions and thus the current system state. Nevertheless, functional feedback is dependent on the task and thus cannot be made available for every task.

10.5.3 Additional Feedback

For Interaction Styles & Feedback (cf., Chapter 7.2) we offered different manifestations of additional feedback, but we did not find any effect on performance or error ratio even compared to no feedback at all. However, participants did strongly argue for feedback as they otherwise did not know whether their interaction was correctly tracked and executed by the system. This was also true for graspable interaction, which still offered the most haptic inherent feedback.

While we did not see any measurable effect in the Interaction Styles & Feedback study we did find an effect on task performance for the Unadorned Desk 2D, with participants being slower when feedback was provided. While in the first mentioned study we showed the feedback after the interaction, we already showed feedback during the interaction with the Unadorned Desk 2D (cf., Chapter 8.1). Participants themselves stated that with feedback present they started to search for items in off-screen space instead of relying on their memory. Moreover they felt pressured to interact more precisely. Especially the latter is not intended by peripheral interaction as it targets coarse and imprecise interaction. Nevertheless participants made more errors when asked to retrieve small items without feedback. Thus, to limit additional visual feedback, and thus decreasing visual attention and potentially speed up the process, the system needs to be properly designed (cf., Chapter 10.4) to be still operable. Nevertheless, we did not evaluate auditory additional feedback as it is often unsuitable in desk-based office scenarios. Future work should assess the advantages and drawbacks of additional auditory feedback compared to additional visual feedback for peripheral interaction.

10.5.4 General Remarks on Feedback

Generally feedback ensuring participants during interaction is no new insight for human-computer interaction. However, as peripheral interaction wants to minimize cognitive load and thus also should limit mental resources for the interpretation of feedback, whenever possible, we strongly argue for functional feedback. If this is not possible, additional feedback should be available but at best as feedback about successful (or failed) interaction and not already during interaction as this may slow down interaction. Nevertheless, of course users should be able to get (on demand) information about the system, its state and its functions in case they forgot about for instance placements of items in off-screen space.

10.6 Dominant vs. Non-Dominant Hand

Whether peripheral interaction is better carried out with the dominant or the non-dominant hand has not been assessed yet by related work. We also did not explicitly target that question however we made several observations about it during the deployments of all our systems.

The question regarding interaction with the dominant or non-dominant hand not only targets the handedness but the location of devices. Thus, during the in-situ deployments of StaTube, Appointment Projection and the Peripheral Music Controller we observed that participants had the tendency to place the peripheral devices on the side of their dominant hand (which usually was the right side). However, when we offered both interaction volumes – left and right of the keyboard – in parallel (cf., Unadorned Desk 3D) both volumes were used equally. We also were not able to measure any statistical difference in terms of performance, offset or errors when comparing interaction in the left of right interaction area or volume for both manifestations of the Unadorned Desk (cf., Chapter 8), thus for touch as well as freehand interaction. Nevertheless we do not have any measured proof that graspable interaction can be performed equally well with the dominant and the non-dominant hand and participants stated that they perceived grasping a device more difficult with the non-dominant hand as it felt like a rather precise movement.

Motoric capabilities are undoubtedly better developed for the dominant hand [91], however in desk- and computer-based scenarios this hand usually is occupied by either mouse or keyboard, while the non-dominant hand would be free for interaction while only using the mouse with the dominant hand. In contrast, the dominant hand already is very accustomed to move between the keyboard and another device (usually the mouse). Annett and Bischof [11] argue that using the dominant hand is a habit one needs to be reminded to break. If encouraged to use the non-dominant hand participants are comparable successful during task execution (they investigated stroke-based touch input) and thus they observed an "increase [in] productivity and [...] also input bandwidth" [11]. Peripheral interaction of course is not limited to stroke-based touch input, but generally targets coarse and simple interactions, thus we believe adapting to use the non-dominant hand is possible for many peripheral interactions and should be addressed more in the future.

10.7 Evaluation

When building devices supporting peripheral interaction a design process and evaluation methodologies are needed. As we previously stated, evaluating peripheral interaction is inherently difficult as the periphery is a very intangible concept that people are often not aware of. To assess peripheral interaction in different stages of the design process we were inspired by evaluation methods from ambient information as well as multitasking research. We used in-situ deployments but also designed a lab evaluation method for early testing, which was by no means aiming at replacing in-situ deployments but to enrich evaluation and the iterative design process for peripheral interaction (cf., Chapter 9). We here summarize some general implications and suggestions for evaluating peripheral interaction at different stages of the development.

10.7.1 Lab-Based Experiments

When looking back at Table 9.3 one can get the impression that one can learn much more from a lab-based evaluation. However, this is merely a question of perspective and current research focus.

Our lab evaluation of the Peripheral Music Controller (cf., Chapter 9.3) uncovered *usability issues*, which would have been very helpful to have known beforehand. We also did find these issues during the in-situ deployment (cf., Chapter 7.1.4), however, we probably could have strengthened our results if the usability problems would have been solved beforehand. Moreover the lab study gave us the possibility to *directly observe participants*, which would not have been possible for the in-situ deployment where participants used the devices at home. This direct observation offered insights on visual attention that we were not able to derive from the in-situ deployment, where we only could log the focus of the audio player window. However, this did not give coherent insights when comparing it to the gazes towards the devices. The lab study also gave us insights on *performance in a primary task* while also using the secondary devices. As peripheral interaction is designed to disrupt any other primary task only as little as possible, this can be used to compare different designs. However, we want to remind that performance is not necessarily the most important goal for a user [167], thus this measurement should not be over-interpreted, but act as weak indicator in relation to other results. Moreover, comparison to a baseline measurement (usage of the connected application, for instance Skype, without the peripheral device, for instance StaTube) can be beneficial to explore behavior changes.

Generally, all rules that are usually applied to lab-based studies in human-computer interaction also apply here. However, previous work did hardly make use of early lab-based testing for peripheral interaction. We showed that one can derive meaningful results for peripheral interaction in a lab study and thus strongly recommend incorporating them in the design process for peripheral interaction, especially for different stages and prototype fidelities. Moreover, while we only brought back the participants from the in-situ deployment to verify our study methodology, we believe this approach can also be used to get deeper insights after an in-situ deployment. For instance to observe visual attention and generally the behavior during interaction with a device after using it over a longer period of time (e.g., we detected that participants adopted a sloppier interaction style than participants who did not use the device before).

10.7.2 In-Situ Deployments

In contrast to lab evaluations, in-situ deployments offer insights on the *integration of devices into daily life*. We were able to assess, which devices were able to "replace" traditional interaction with mouse and GUI. Moreover we could observe details such as the preferred location of a device. We here found that in most cases participants placed devices on the side of their dominant hand. Nevertheless we are hesitant to conclude from this that peripheral interaction can be better executed with the dominant hand as many people just might use their dominant hand out of habit (cf., Chapter 10.6) [11].

Most interestingly we observed usage of devices that we would not have anticipated beforehand. For example with the Peripheral Music Controller (cf., Chapter 7.1) we observed that participants enjoyed the possibility to carry around the touch device to control the player from other locations than their desk.

Finally, effects such as the novelty effect can only be overcome with the help of an in-situ deployment. However, we found that two weeks are often not enough to achieve a complete shift to the periphery and to habituate peripheral interaction (cf., Chapter 10.2). Furthermore, unforeseen events such as job changes or spontaneous holidays might further affect the duration for a participant with a device (cf., StaTube, Peripheral Music Controller). Of course, this among other effects are true for all in-situ deployments, independent whether they target peripheral interaction or not. Still we believe in-situ deployments are especially essential for peripheral interaction as only through long-term deployments devices can shift to the periphery.

10.7.3 Evaluation for Peripheral Interaction in General

Apart from the two basic categories, other evaluation styles of course are also imaginable and future research in the field of peripheral interaction should explore them. Thus, this chapter can only offer first insights into evaluation of peripheral interaction.

Apart from the lab-based evaluation we already made a first step into exploring paper-based prototypes for early testing. We found that our paper-based devices were very successful to find suitable mappings for each available interaction (cf., Chapter 7.1.2). However, further results could not be derived from that, for instance we asked, which device (here: graspable, touch, freehand) they would prefer for interaction and rankings completely differed compared to the in-situ deployment with the implemented devices. Thus, paper-based prototypes seem to be too abstract (no interactivity, different haptic) to imagine real usage properly.

Overall we consider lab studies – with paper-based prototypes as well as high fidelity working devices – to be very useful to get the "right" design, spot usability issues and compare alternatives. These early explorations then foster subsequent successful in-situ deployments. Thus the question is not lab vs. in-situ but which evaluation at which step of the design process, to make use of the iterative design process.

Chapter 11

Roundup & Future Work

In this thesis we explored the design space of peripheral interaction. After reviewing related literature, we therefore proposed a theoretical classification for peripheral interaction along six axes and further added a perspective on peripheral task types as basis for categorization of peripheral devices and to span a design space.

In more detail we explored three manual interaction styles – graspable, touch and freehand interaction – with an approach based on six probes – StaTube, Appointment Projection, Peripheral Music Controller, Interaction Styles & Feedback, Unadorned Desk 2D and 3D – related to a standard computing scenario.

We found that peripheral interaction was preferred over traditional input with mouse and keyboard for secondary side tasks, which fostered the execution of tasks that otherwise often might have been neglected. Moreover we managed to reduce cognitive and visual load for all investigated interaction styles when comparing them to traditional user input on a computer.

Finally, during the development of our six prototypes, we applied different evaluation strategies including in-situ deployments over a longer period of time as well as lab-based experiments. Moreover we developed a methodology for testing peripheral interaction in the lab and compared our prototypes to peripheral everyday tasks such as drinking, switching on the light or watching TV.

11.1 Contributions

With this thesis we set out to answer two research questions: (1) How can the design space for (manual) peripheral interaction be extended beyond graspable or tangible interaction? And (2) how can the design process for peripheral interaction be enriched, especially which evaluation methodologies can be successfully applied to peripheral interaction?

With this thesis we answered both questions and thereby offer three overall contributions to the field of peripheral interaction.

11.1.1 Classification

We proposed a classification for the design space of peripheral interaction (cf., Chapter 5), which consists of six axes – explicitness, input, proximity, granularity, privacy and feedback. While we solely focus on explicit manual (thus bodily) peripheral interaction, consequently interaction close by, we cover each characteristic of the other three axes in at least one of our projects, as we relied on probes for different manifestations inside this design space. Moreover we not only assessed peripheral interaction and its parameters but also offered a categorization for potential tasks that can be supported by peripheral interaction. We addressed every task category by several prototypes in this thesis. In summary, apart from the theoretical classification itself, we offer a broad first glimpse into the design space of peripheral interaction and its associated tasks through different prototypes but no in-depth analysis of one specific aspect of peripheral interaction. With peripheral interaction being a very new research area, we believe this to be a suitable approach getting first practical insights on the benefits and overall appeal of peripheral interaction. The classification can guide researchers to uncover alternative strategies for peripheral interaction as well as offer a way to position their peripheral design.

11.1.2 Design Implications

In the course of this thesis we built six prototypes and evaluated them in several studies in the lab as well as in in-situ deployments for several weeks. From each project we derived lessons learned for designing peripheral interaction. We finally summarized these lessons in Chapter 10 to offer a general overview on benefits as well as limitations for future peripheral interaction design. Benefits among others include peripheral interaction offering a shortcut to functionality but also extending functionality. We further discussed learnability as well as habituation. While the first is usually simple for peripheral interaction, the real chore is to break old habits and to embrace peripheral interaction as new habit. We further assessed visual and mental attention, which both should be low for successful peripheral interaction. While we generally consider all three interaction styles to be fit for peripheral interaction, we discussed specific benefits and drawbacks for the three interaction styles that we investigated for manual peripheral interaction. Being part of the classification, we further revisited the three feedback types – inherent, functional and additional feedback – and reviewed their impact on successful peripheral interaction. Moreover we briefly assessed the usage of the dominant and non-dominant hand for peripheral interaction, and encouraged to also design for interaction with the non-dominant hand. While all these findings are not conclusive for peripheral interaction, we believe that they cover broad insights into peripheral interaction, which can guide future projects.

11.1.3 Evaluation Strategies

When exploring a new research field, the design process and especially evaluation methodologies are not yet established. This also holds true for peripheral interaction, however, related fields such as ambient information and multitasking act as inspiration. Through the development of the six prototypes we applied several evaluation strategies including early testing based on paper-based prototypes and lab studies relying on dual-task scenarios as well as in-situ deployments for several weeks. As we observed a lack of evaluation, especially in the early development stages, we developed a lab-based evaluation method and assessed its validity through a case study comparing results from an in-situ deployment with the results from the lab study using this methodology and found comparable results (cf., Chapter 9). We used this methodology not only to assess our peripheral tasks but also investigated the impact of everyday peripheral tasks such as drinking or switching on the light. These results can act as comparison for peripheral digital tasks, which were investigated using this methodology. In Chapter 10.7 we further summarize implications for the evaluation of peripheral interaction, especially which study type fosters which results for instance concerning visual and attentional periphery or suitability of a gesture set for peripheral interaction.

11.2 Limitations & Future Work

As repeatedly stated, peripheral interaction is a new research area and thus there is obviously plenty of room for future work. Despite the wide range of projects, which are the basis of our implications for peripheral interaction, there are certain limitations in our work. Although we handed our prototypes to participants for several weeks we cannot rule out the novelty effect completely. To truly embed a new type of interaction into daily routines more time is needed. Still we see our findings as a good indicator for the general feasibility of peripheral interaction. Further open questions include specific parameters, to name one for instance the size of the tracking area. As the Interaction Styles & Feedback study (cf., Chapter 7.2) showed, the bigger interaction area increased subjective ratings for touch and freehand interaction and reduced visual attention even more compared to the Peripheral Music Controller (cf., Chapter 7.1). However, having a bigger interaction area also increases the risk of unintended commands, while the Peripheral Music Controller was successfully tested in an in-situ deployment and did not lead to tracking of unintended gestures, for the second setup, the Interaction Styles & Feedback study, we do not have data on interference with other interactions carried out around the desk. However, we believe that such parameters are dependent on the use case, the setting of the primary task as well as the peripheral task. We therefore are very skeptical on offering hard data and believe that to some extent these parameters have to be defined individually for every project for instance with early lab-based approaches such as the one proposed in this thesis. We therefore focus the listed future work on more general issues that we observed during our evaluations or that we generally believe to be beneficial extensions to the field of peripheral interaction.

11.2.1 Integrating Peripheral Interaction

Our work as well as projects from related work [23, 25, 26, 70, 189] rely on separate devices to offer peripheral access. This offers several advantages such as a clear mapping between device and task as well as the possibility to design the peripheral device precisely according to the current needs. On the other hand it is not feasible to equip people with one distinct device for each individual side task as it also imposes scaling issues. While our prototypes were merely designed to investigate different attributes of peripheral interaction, the next iteration of devices needs to address adaptability to different tasks and use cases. The Unadorned Desk (cf., Chapter 8) is a first step into this direction as we can imagine many different items, commands or applications being connected to it and thereby stored and retrieved in the periphery. Moreover, research should investigate how peripheral interaction can be achieved with only minimal additional (tracking) devices. On a desk based scenario this could include approaches such as integrating touch and freehand tracking into existing devices such as mouse, keyboards and displays but also surrounding items such as the furniture for instance the desk itself. For non stationary use cases (cf., Chapter 11.2.3) this is even more important as every additional device would require participants to carry them, which is at best inconvenient but often not even possible.

11.2.2 Increasing Physicality for Touch and Freehand Interaction

During the exploration of touch and freehand gestures in comparison to graspable interaction we observed that the physicality offered by graspable devices is very beneficial for peripheral interaction as it assures users that their actions are tracked. Touch devices still offer some physicality as users can feel the tracking surface, however, especially for discrete touch this still does not offer feedback about the current location of the touch. In addition to it, freehand gestures lack any physicality and do not offer feedback whether the users have positioned their hand inside the tracking area. To overcome this issue for touch input researches explored textures and shapes such as holes as guidance [210]. We believe such approaches can be adapted to offer support for a variety of peripheral tasks. For freehand tracking offering physical boundaries might help locating the freehand tracking area, however this might also unnecessarily limit the user during approaching the tracking area. Future research needs to tackle this trade off and explore other means of overcoming the lack of physicality for freehand gestures, potentially by applying remote tactile feedback [205].

11.2.3 Investigating Mobile Peripheral Interaction

Our focus in this thesis was on desk-based scenarios. Related work did some explorations for the target group of primary school teachers, who during work walk through the classroom and thus frequently switch location [23, 25, 26]. These peripheral devices were designed to be worn around the wrist or clipped on clothes. However, these devices were still often used while placed on a table [25]. Generally, many other, less stationary scenarios can be imagined and need to be investigated. Especially mobile devices such as smart phones are often used on the go, which not only is cumbersome but imposes danger on the users while navigating through traffic. Research already picked up on that and investigates eyes-free interaction for mobile scenarios [265]. However, as thi s thesis should have strengthened, reducing visual attention is only one aspect of peripheral interaction and especially cognitive load should also be considered. Moreover, several projects employ the body for input (e.g., [97]), expecting miniaturization of sensing devices, this type of interaction is especially of interest because it uses the always available body and thereby makes use of bodily capabilities thus offering an interaction that relies on physicality, which is as stated very beneficial for peripheral interaction. With this in mind, the overall application area of peripheral interaction should be increased addressing many different scenarios and user groups such as athletes [187], drivers [158] and many others [20, 99].

11.2.4 Including Feedback

In this thesis we observed that functional feedback is powerful in assuring users of their interaction. If the interaction style also provides considerable inherent feedback for instance through its physicality people do not miss additional feedback. However, many tasks do exist that do not offer functional feedback and as reported, moving from graspable interaction to touch and freehand interaction physicality is reduced. Thus for some tasks additional feedback for peripheral interaction is inevitable. In this thesis we only investigated visual feedback, which is a suitable choice for desk-based and office-based scenarios in which audio feedback might disturb co-workers. Work by Bakker et al. [24, 25, 26] already investigated soundscapes as feedback, while additional haptic feedback has not been used at all to support peripheral interaction. Moreover, feedback up to now only was used to offer information about an interaction that was already carried out. However, feedback (or rather feedfoward [240]) can also be applied to guide the interaction, for instance locating the tracking area for freehand tracking. Inevitably, in the scope of peripheral interaction, it is not only important to investigate whether people do understand the feedback and whether the mapping between the interaction and the feedback is coherent, but also how peripheral or ambient this feedback can be perceived with only minimal distraction.

11.2.5 Improving Evaluation for Peripheral Interaction

We already tried to give an overview of different evaluation methodologies for peripheral interaction during different stages of the design cycle. However, as our focus was on desk-based scenarios our evaluation methodologies, especially for the lab, target desk-based settings and can only be partially transferred to other use cases. We further still only made use of a limited set of evaluation methods for instance completely neglecting analytic approaches. Moreover, although peripheral interaction actually is a field, which tries to uncover long term effects and researchers regularly deploy their devices for several weeks, we still lack findings on real life everyday use for an extended period time as for example provided by John Hardy and his report on working on an interactive desk for one year [95, 96].

11.3 Closing Remarks

This thesis offers a first glimpse into peripheral interaction, especially through graspable, touch and freehand interaction. We strongly believe that digitalization will continue to find its way in our everyday lives and human-computer interaction needs to find ways to support this omnipresence of and interaction with digital devices. One approach postulated for several years now is context awareness. However, we believe that context awareness in many settings is technically hard to achieve or impossible at all but more importantly undermines the users who at last should be in charge of their interactions. Peripheral interaction is one way to offer the users freedom of interaction by better integrating interaction into daily life and therefore support physical, social and mental demands [196] thus offering interaction which minimizes interference of senses, hence offering parallelization and reducing disruption as well as stress. Our use cases were only examples targeting very frequent side tasks. We did this for purely practical reasons such as having a sufficient pool of users to explore these systems. However, other more specialized use cases can be imagined (for instance distinct user groups such as drivers or waiters). For domain experts with very special needs and elaborate routines (e.g., medical staff) even more complex interactions could move into the periphery, just as in the physical world, physically very complex tasks – such as walking or typing – can become peripheral with enough training. With new devices – for instance currently Google Glasses and smart watches – hitting the marked, more peripheral interaction techniques will emerge but also be necessary to ultimately reduce visual and cognitive demand and reduce the need for attention for many interactions.

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Eidesstattliche Versicherung

(Siehe Promotionsordnung vom 12.07.11, § 8, Abs. 2 Pkt. 5)

Hiermit erkläre ich an Eidesstatt, dass die Dissertation von mir selbstständig und ohne unerlaubte Beihilfe angefertigt wurde.

München, den 16. Oktober 2013

Doris Hausen