Informatics

Promoting Uptake of Utilitarian Cycling Through Digital Technology

DISSERTATION

submitted in partial fulfillment of the requirements for the degree of

Doktor der Sozial- und Wirtschaftswissenschaften

by

Matthias Wunsch, MSc, BSc
Registration Number 0752404

to the Faculty of Informatics

at the TU Wien

Advisor: Prof. Geraldine Fitzpatrick, PhD

The dissertation has been reviewed by:

Susanne Boll

Markus Rittenbruch

Vienna, 18th September, 2022

Matthias Wunsch

Technische Universität Wien
A-1040 Wien ▪ Karlsplatz 13 ▪ Tel. +43-1-58801-0 ▪ www.tuwien.at

Erklärung zur Verfassung der Arbeit

Matthias Wunsch, MSc, BSc

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

Wien, 18. September 2022

Matthias Wunsch

Acknowledgements

This thesis is marks the end of a long journey to grow as a person, academic and researcher. I am deeply thankful to my parents, who throughout my life supported and encouraged me in so many ways, including my educational and academic path. They also instilled enough self-confidence in me for taking on a challenge such as doing a PhD.

I could not have done this without the loving support of my wife Beate. She believed in me, motivated me, provided feedback, and helped me whenever possible. Thank you so much!

It was the AIT Austrian Institute for Technology that provided the opportunity to me to work on this theses. And it would not have been the same without my former colleagues and project partners: Dr. Alexandra Millonig, Dr. Stefan Seer, Dr. Agnis Stibe, and Ryan CC Chin, Ph.D. Thank you!

I was lucky enough to start my PhD journey together with – by now Dr. – Silvia Klettner, who has been my PhD buddy ever since. We shared so many doubts, insights, frustrations, ideas, and a good friendship that helped me along this journey. I want to thank my thesis examiners, Prof. Dr. Susanne Boll and Assoc. Prof. Markus Rittenbruch, PhD, for their thorough examination of and valuable feedback for this thesis. I am thankful to many of my colleagues from TU Wien's HCI group. Thank you to Dr. Petr Slovák for supporting me with both his critical thinking and overwhelming excitement for doing research. I want to thank Franziska Tachtler, Laura Scheepmaker, and Isabel Schwaninger for being part of our PhD writing group. They provided valuable help and feedback, and more than this, having each other made finishing this PhD thesis a much less lonely experience. I also want to thank Dr. Irene Posch for all the good discussions and feedback. I want to thank Dr. Peter Purgathofer, who I had the joy to call colleague, and from whom I have learned so much about design and software's role in our society over the years. A warm thank you also goes to Dr. Chris Frauenberger and Dr. Florian Güldenpfennig, for all the good discussions we had.

Above and beyond I want to thank Prof. Geraldine Fitzpatrick Ph.D. With her wisdom, support, empathy, and feedback, she has been so much more than a supervisor to me. She managed to stay critical of my work while always being supportive and positive. Her mentorship throughout those years meant that she did care deeply about me and my work, and that she gave me room to grow. I am deeply thankful for the influence she had on me, as she shaped my way of thinking, of working with others, and of leading.

Abstract

Information and communication technologies (ICT) are becoming ever more pervasive in our everyday lives. Mobility, including all modes of transport, is one area where this trend is present. However, there is no comprehensive understanding of technology's role in supporting utilitarian cycling in realistic everyday settings. In this thesis, I aim to address this gap by exploring the interplay of technology and the adoption of utilitarian cycling. Across seven case studies, I describe motivations, choices and experiences involved in utilitarian cycling and the role of technology therein. I furthermore lay out how the environment, the available cycling infrastructure, the complex interactions with other road users, and the competencies of individuals shape experiences during cycling and using ICT in that realm. Using technology probes incorporating game-like elements, I show how such systems can help their users to stay motivated and use the bicycle more often. I also investigated how professional cycling instructors help novice cyclists to inform the design of a technology probe that facilitates competence development to support cyclists in complex real-world contexts. Its evaluation shows the potential and limits of such a supportive technology. By connecting the findings across the case studies back to the literature, I then present a framework for HCI in utilitarian cycling. Therein I show that utilitarian cycling can be understood as a practice that is itself a composition of smaller sub-practices, each of which consists of a dynamic interplay between material things, competences, and meanings. These practices can then be distinguished into those that happen on-the-bicycle and those off-the-bicycle. Furthermore, those practices differ in their complexity. I identify four fields of practices – planning practices, choosing utilitarian cycling, manoeuvring practices, and handling practices – and show how my case studies and related work in HCI research contribute to understanding the role of digital technology within those practices.

This thesis contributes to HCI research by presenting a condensed conceptual perspective for HCI interventions and utilitarian cycling. It ranges from an abstract and decontextualised to a specific and contextualised view on cycling. It provides a detailed description of cyclists' experiences within complex real-world contexts, highlights the importance of both choices and social practices, and provides an understanding and examples for designing and embedding ICT as meaningful support in this realm. The insights presented here can thus inform future research and design on interactive technology for cycling.

Kurzfassung

Informations- und Kommunikationstechnologien (IKT) werden stetig zu einem wichtigeren Teil unseres Alltags. Dieser Trend ist auch in allen Formen von Mobilität präsent. Derzeit gibt es jedoch kein umfassendes Verständnis der Rolle von IKT für die Unterstützung von Radfahrenden. Ich adressiere diese Forschungslücke indem ich das Zusammenspiel von Technologie und Radfahren für Alltagszwecke erforsche. Anhand von sieben Fallstudien beschreibe ich die Rolle von Technologie für die Motivation, Entscheidungen und Erlebnisse von Alltagsradfahrenden. Darüber hinaus lege ich dar, wie die Umgebung, die verfügbare Fahrradinfrastruktur, die komplexen Interaktionen mit anderen Verkehrsteilnehmer*innen und die Kompetenzen Einzelner die Erfahrungen beim Radfahren und der Nutzung interaktiver Technologien in diesem Bereich prägen. Anhand von Technologieinterventionen mit spielerischen Elementen zeige ich, wie solche Systeme ihren Benutzer*innen helfen können, motiviert zu bleiben und das Fahrrad häufiger zu nutzen. Ebenso untersuchte ich, wie professionelle Fahrradlehrer*innen unerfahrenen Radfahrenden helfen. Anhand dieser Erkenntnisse habe ich einen Prototyp entwickelt und evaluiert, welcher Radfahrende in komplexen realen Kontexten unterstützt und deren Kompetenzentwicklung fördert. Indem ich die Ergebnisse der Fallstudien mit relevanter Forschungsliteratur verbinde, präsentiere ich ein konzeptionelles Modell für die Rolle von Mensch-Computer-Interaktionen im Radfahren. Darin zeige ich, dass alltägliches Radfahren als eine Soziale Praktik verstanden werden kann, die selbst eine Zusammensetzung kleinerer Teilpraktiken ist. Diese können wiederum als dynamisches Zusammenspiel aus Dingen, Kompetenzen und Bedeutungen verstanden werden. Im Zuge dieses konzeptionellen Modells unterteile ich Teilpraktiken in jene, die auf dem Fahrrad, und solche, die abseits des Fahrrads stattfinden. Darüber hinaus unterscheiden sich diese Praktiken in ihrer Komplexität. Somit identifiziere ich vier Bereiche von Praktiken: planen, entscheiden, manövrieren und handhaben. Ich zeige die potenzielle Rolle von IKT innerhalb dieser Praktiken anhand meiner Fallstudien sowie veröffentlichter Forschungsarbeiten auf.

Ein Beitrag dieser Dissertation zur HCI-Forschung liegt daher in diesem konzeptionellen Modell für HCI-Interventionen im Radverkehr. Darin wird der Einsatz von IKT beim Radfahren in einer abstrakten und dekontextualisierten bis hin zu einer spezifischen und kontextualisierten Form thematisiert. Darüber hinaus liefere ich in dieser Dissertation eine detaillierte Beschreibung der Erfahrungen von Radfahrenden in komplexen realen Kontexten, und hebe die Bedeutung sowohl von Entscheidungen als auch von sozialen Praktiken hervor. Die hier vorgestellten Erkenntnisse können somit für zukünftige

Forschung zu und Design von Informations- und Kommunikationstechnologien für das Radfahren genutzt werden.

Published Work

Peer-reviewed Publications

Wunsch, Matthias and Geraldine Fitzpatrick (2021). „Complex Contexts and Subtle Actions: Design and Evaluation of a Virtual Coach for Utilitarian Cycling“. In: Human-Computer-Interaction – INTERACT 2021. Ed. by Carmelo Ardito et al. Cham: Springer International Publishing, pp. 125–146.

Wunsch, Matthias, Alexandra Millonig, Stefan Seer, Katja Schechtner, Agnis Stibe, and Ryan C.C. Chin. (2016). „Challenged to Bike: Assessing the Potential Impact of Gamified Cycling Initiatives“. In: Transportation Research Board (TRB) 95th Annual Meeting 2016. January 10–14, 2016. Washington, DC.

Wunsch, Matthias, Agnis Stibe, Alexandra Millonig, Stefan Seer, Chengzhen Dai, Katja Schechtner, and Ryan C.C. Chin (2015). „What Makes You Bike? Exploring Persuasive Strategies to Encourage Low- Energy Mobility“. In: Persuasive Technology. Ed. by Thomas MacTavish and Santosh Basapur. Lecture Notes in Computer Science. Springer International Publishing, pp. 53–64.

Peer-reviewed Position Papers

Wunsch, Matthias (2021). „Evaluation of Interactive Systems for Cyclists Using Wizard of Oz Prototypes In-The-Wild.“ For: Cycling@CHI: Towards a Research Agenda for HCI in the Bike Lane. In CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI ’21 Extended Abstracts), May 8–13, 2021, Yokohama, Japan. ACM, New York, NY, USA, 5 pages.

Editor-reviewed Publications

Wunsch, Matthias, Alexandra Millonig, Stefan Seer, Katja Schechtner, Agnis Stibe, and Ryan C.C. Chin (2016). „Gamification and Social Dynamics: Insights from a Corporate Cycling Campaign“. In: International Conference on Distributed, Ambient, and Pervasive Interactions. Springer, pp. 494–503.

Contents

CHAPTER 1

Introduction

We are living in a time of ever-present change, technological advancements and growing economic activity. With these trends come new challenges for both individuals and society. Within the area of transportation, cycling can help to address those challenges. On an individual level, utilitarian cycling, that is using the bicycle as part of one's everyday routines to derive utility such as getting to a desired location or transporting goods, is time- and cost-efficient for short distances (Gössling and Choi 2015). It helps to stay physically active, thereby resulting in immediate health benefits such as lowering the risks of cardiovascular disease, cancer, and other causes of mortality (Dinu et al. 2019; Celis-Morales et al. 2017). It even brightens one's mood (A. Martin, Goryakin, and Suhrcke 2014; Morris and Guerra 2015). On a societal level, cycling represents a low-emission, space-efficient and environment-friendly mode of transport that can contribute to an ecologically sustainable development, especially in an urbanizing world that is challenged by global climate change (IPCC 2021; Nations 2014). However, the benefits of cycling are not imminently present when adopting it for commuting or other personal transportation needs. The actual experience of using cycling for one's personal transportation can be rather understood as jumping through hoops: One needs the skills to control a bicycle, do so within complex environments, navigate while often relying on only a mere patchwork of bicycle lanes which may be in varying conditions, while being exposed to the elements, and meet one's daily requirements such as shopping, carrying equipment or transporting others (Pucher, Dill, and Handy 2010). Travel times can be prohibitive, and one needs, of course, access to a bicycle – either through owning a bicycle or renting out a shared bike. With that comes the necessity to securely store or return the bicycle. In a recent study, a population of 3.000 persons from 50 U.S. metropolitan areas was surveyed about their transportation routines. Therein, 10% used a bicycle for transportation in the last 30 days, and over 50% of the respondents were "interested but concerned", that is: they are physically able to ride but are uncomfortable with riding on a major street without or with a bike lane, and neutral to interested in riding more

(Dill and McNeil 2016). Altogether, a set of material qualities and competencies need to be combined to integrate a practice like utilitarian cycling in one's everyday life. This is also where opportunities for the design of digital technologies for promoting the uptake of utilitarian cycling emerge.

1.1 Motivation

As computing is becoming ever more ubiquitous in our everyday activities, HCI has entered the field of personal transportation. Cars are a striking example of how interactive, computational technology became a more present part of the transportation experience within the past decades. There are already trends pointing to a similar shift in the material quality of the bicycle: The market share of electrified bicycles is growing continuously, which changed the riding experience and reach for many cyclists. Bike-sharing schemes depend on internet-connected services to enable their operations. Electronically enabled capabilities on the bike such as built-in theft protection and tracking systems, remotely controlling a bike lock, or smartphone charging are becoming more prevalent.[1] The widespread use of smartphones and wearable devices also makes it easy to use software applications on the bicycle, e.g., turn-by-turn navigation or fitness tracking. Given these opportunities, interactive technologies and assistive systems for utilitarian cycling are becoming more relevant in research and commercial products.

Human-computer interactions on the bike have been researched from different angles thus far. On the one hand, the effectiveness of different interaction modalities has been studied. Those range from auditive, vibrotactile or visual interfaces for cyclists which have been evaluated (Steltenpohl and Bouwer 2013) or compared (Waard et al. 2017; Matviienko, Ananthanarayan, El Ali, et al. 2019; Poppinga, Pielot, and Boll 2009; Steltenpohl and Bouwer 2013). Use cases have often been navigational guidance but also included context-aware sensing to help cyclists regulate their speed to cross traffic lights on green (Andres et al. 2019) or means to deliver warnings for children while cycling (Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. 2018). On the other hand, research in the field of HCI for cycling emphasised change towards active transportation. This typically involves systems designed to sense and reveal information about a user's transportation choices with some form of prompts to choose more active or environmentally friendly options (e.g., Froehlich, Dillahunt, et al. 2009; Broll et al. 2012; Gabrielli, Maimone, et al. 2013; Semanjski et al. 2016; Wernbacher et al. 2015). This approach has also been extended with gamified designs (Broll et al. 2012; Gabrielli, Maimone, et al. 2013; Wernbacher et al. 2015).

[1] Companies like Van Moof, Econicone or Stromer are offering e-bikes with integrated theft protection, location detection, and app connectivity to configure riding characteristics or allow remote maintenance. See
https://www.vanmoof.com/
https://www.stromerbike.com/
https://econicone.com/

There are, however, only a few accounts that bridge these angles to provide a comprehensive understanding of the role information and communication technology could have for supporting utilitarian cycling [2] in realistic everyday settings. There is a limited understanding of the experiences of people adopting cycling as an everyday practice. There is also little work that provides a structure for situating information and communication technology (ICT) within cycling as an everyday activity. Few studies across research disciplines investigated cyclists while using such ICT systems in real-world scenarios. Therefore, the research questions within this thesis move beyond immediate interactions between a person and a digital system to understand the role of technology from a broader perspective. They are thereby asking for the interplay between interactive systems, complex everyday contexts of cycling, and transportation mode choices, which have not been explored to date.

1.2 Research Questions and Contributions

This thesis aims to understand the practices within utilitarian cycling and how those can inform design and research on information and communication technology for supporting cyclists. The overarching question thereby is: **How can information and communication technology promote the uptake of utilitarian cycling?** Given the breadth of this aim, this thesis is grounded on seven case studies that explore the space for human-computer interactions in the realm of cycling, thereby providing pointers and guidance to research and design in that field.

To achieve this, three main research questions guide the work within this thesis:

- *RQ1: How does the introduction of information and communication technology to promote cycling affect the uptake of utilitarian cycling?*
- *RQ2: How can information and communication technology provide motivational support for the choice to cycle?*
- *RQ3: How can information and communication technology facilitate in-the-moment support for cyclists?*

The first research question asks for the relationship between the use of interactive systems and the choice to use a bicycle. It particularly asks for examples of adopting cycling for everyday transportation needs due to the introduction of such systems. An initial set of three case studies offers first answers to this question. They also motivate the subsequent design and research, which explore a more indirect relationship between interactive systems and the uptake of cycling along two avenues: Motivation to choose to cycle and experiences of cycling. The former is tackled by the second research question, which asks about the relationship of motivation to cycle and information and communication

[2] A comprehensive definition of the term "utilitarian cycling" is included in Chapter 2 and the appendix.

technology, thereby exploring the dynamics behind transportation choices. I probe into this by studying interventions designed to promote riding a bike for one's transportation needs. The designs that are evaluated here are grounded in insights on motivation in social settings. They also introduce game-like design elements like teams, leaderboards, and challenges. With research question three, I then move to the in-the-moment experiences of cyclists. Motivated by the insights and a critical discussion of previous findings, competencies and coping strategies involved in the practice of utilitarian cycling become a central point for understanding the experience of cycling. This is guided by the insight that being able to skillfully apply competencies enables an individual to ride a bicycle within a given context. Experiences that emerge within the built infrastructure are taken into account, and coping in real-life situations is emphasized. I probe into this with a novel approach for competence development for cycling using a prototype of a Virtual Cycling Coach within a real-world cycling scenario. I explore how ICT can bring positive change to the cycling experience by offering in-the-moment, in-the-wild support for competence development.

Beyond this empirical work, I present a conceptual framework (Maxwell 2008) for HCI in the realm of cycling. This framework is informed by existing work and the findings from the presented case studies. It offers an empirically grounded wild theory, i.e. an embodied and ecological theoretical understanding of how people use bicycles (Rogers 2012), for the role of ICT for the practice of cycling. It is concerned with the range from abstract and decontextualised to specific and contextualised aspects of cycling. Cycling is viewed as a social practice that is composed out of multiple smaller practices, each existing through the combination of materials, competences and meanings (Shove, Pantzar, and Watson 2012). I provide further answers to research question 1 by showing how information and communication technology is and could be included in those practices.

With the answers to these research questions, I contribute to HCI research by providing a detailed description of the role of information and communication technology in the choice to use the bicycle. I also offer an understanding of cyclists' experiences within complex real-world contexts, which can inform the design of information and communication technology for meaningful *in situ* support. Beyond these main empirical contributions, this thesis provides a conceptual framework for HCI and utilitarian cycling that can be used to structure research and inform the design of interactive technologies. By mapping existing HCI research and the studies presented in this thesis to that framework, I show where there is already substantial knowledge and where there are gaps related to HCI for utilitarian cycling. With cycling being a relevant mode of transportation for the future, having such a framework for HCI research and design can aid our collective work to advance this area and help when discussing HCI for cycling and the meanings, goals and agendas for information and communication technology introduced in that field.

1.3 Thesis Overview

In this thesis I present seven empirical case studies and a conceptual framework. The flow of research questions, case studies, and contributions is visually represented in Figure 1.1. The chapters do have the following structure:

Chapter 2 presents related work across relevant research disciplines.

Chapter 3 provides a detailed account of the ontological, epistemological, axiological and methodological approaches of this thesis.

Chapter 4 is an initial exploration of possible ICT interventions to answer *RQ1: How does the introduction of information and communication technology to promote cycling affect the uptake of utilitarian cycling?* I present a set of three explorative case studies on the relationship between interactive systems and the adoption of cycling:

- Case Study I – Frequent Biking Challenge: What are the effects of introducing game-like elements to promote the choices to use the bicycle?
- Case Study II – Virtual Bike Tutorial: Can a virtual tutorial on urban cycling skills support the adoption of utilitarian cycling?
- Case Study III – Bike Buddy Program: How do novice cyclists experience being supported by other cyclists?

The first case study introduces the Frequent Biking Challenge as an intervention to promote cycling using an interactive digital system. Findings from this case study align with previous research showing that users did choose cycling more often. At the same time, this case study raises questions about the group dynamics, motivational aspects and long term effects which are tackled in the subsequent chapter. Case study II moves to the role of competencies and the confidence needed for cycling, particularly in more complex urban contexts. I designed an intervention called the Virtual Bike Tutorial that provided training of essential urban cycling skills in a safe setting on the desktop, i.e. on a personal computer. The findings there showed that the intervention was lacking the realism needed for effective experiential learning to happen. In the third case study, I asked how beginning cyclists are supported by experienced cyclists. Without a particular technology intervention, this was carried out to understand a setting that might easily occur within the family, between friends or colleagues. My findings show that different perceptions and experiences between the veteran and novice cyclists present challenges in this setup which otherwise – with its focus on in-the-moment support – can be helpful to beginners. A result cutting across these initial three case studies was the emergence of the differences between technology designed for choices. These differences are investigated in more depth in the subsequent case studies.

Chapter 5 is grounded in the previous findings and critical reflection on the used approaches. I therein tackle *RQ2: How can information and communication technology* *provide motivational support for the choice to cycle?* Building on findings from related work, I present two additional case studies on systems designed to increase choices to cycle. To raise the credibility and transferability of the results, the following research questions guide the studies:

- Case Study IV – Bike to Work: What ICT and campaign designs does the campaign Bike to Work use to encourage cycling? What are the effects of participating in Bike to Work on transportation mode choices?
- Case Study V – Biking Tourney: Can a system designed around playful competition between organizations engage employees in commuting by bike? What group dynamics are introduced by such a system?

Within Case Study IV, I aim at gaining additional insights from an existing campaign to promote commuting by bicycle. In this evaluative study, a clear effect on daily transportation choices could be shown and I describe a useful distinction between groups of participants. Using retrospective questions also revealed longer-term changes and habit formation. Case study V then probes into even more detailed questions by designing and studying an intervention to promote riding the bicycle. The designs were grounded in insights on motivation in social settings and introduce game-like design elements like teams, leaderboards, and challenges. Motivated by the insights and a critical discussion of this approach, I then move to the third empirical chapter that is concerned with ICT to provide in-the-moment support for cyclists (RQ3).

Chapter 6 moves from concerns on the choice to use the bicycle to concerns on the practice of utilitarian cycling. There, the involved competencies and coping strategies become a central point for understanding the experience of cyclists. As being able to skillfully apply competencies is what enables us to live our everyday life, it is also what enables an individual to ride a bicycle within a given context. The guiding research question (RQ3) thus is: *How can information and communication technology facilitate in-the-moment support for cyclists?* This chapter includes two case studies which follow these guiding questions:

- Case Study VI – Teaching and Coaching Beginning Cyclists: What teaching and support methods are used in existing bicycle education and training settings?
- Case Study VII – Virtual Cycling Coach: Can cyclists be meaningfully supported in-the-moment using information and communication technology?

Case study VI shows how professional cycling instructors support novice cyclists, thereby providing insights into the methods for teaching and supporting used in existing bicycle education and training settings. The generated insights are then used to inform the final Case Study VII, that includes the design and qualitative evaluation of the Virtual Cycling

Coach, an interactive system that provides situated training on the bike in-the-wild. This case study asks if cyclists can be meaningfully supported in-the-moment using information and communication technology. I present the findings from a prototype of the Virtual Cycling Coach that was evaluated in real-world, complex contexts. These show that the tested design did create lasting learning experiences and helped to build cycling competencies.

Chapter 7 introduces the Human-Computer-Interaction in Utilitarian Cycling Framework. Here I follow the approach promoted by social practice theory of putting the practice – i.e. the doing – rather than the one who is doing it, at the center. I show that utilitarian cycling can be understood as a practice that is itself a composition of smaller sub-practices, each of which consists of a dynamic interplay between material things, competences, and meanings. Much like atoms bond together to form molecules, the practice of utilitarian cycling is then understood as a composition of these smaller sub-practices. It is as part of those small practices that ICT can either extend or change a practice, or enable entirely new practices. These practices can then be distinguished into those that happen on-the-bicycle and those off-the-bicycle, and a dimension of their complexity. I thus identify four fields of practices: planning practices, choosing utilitarian cycling, manoeuvring practices, and handling practices. On the one hand, planning practices and choices cover aspects happening before or after riding, i.e. not while cycling. This can include planning of a route or preparing one's gear. Choosing utilitarian cycling then emphasises conflicting demands and motivations, such as travel time, cost, or convenience. Handling and manoeuvring practices, on the other hand, are performed while using the bicycle. The former include simple practices for using a bicycle, such as controlling the bicycle in motion, reacting to dangers, or riding in traffic free areas. The latter describe more complex practices, such as navigating while riding, interacting with other traffic participants or owning the safety of others. I then use my case studies and related work in HCI research to show how information and communication technology is embedded into those practices. Thereby I offer additional insights into how it can contribute to the uptake of utilitarian cycling.

Chapter 8 provides a discussion of the work presented in this thesis. I first discuss the relation of the conceptual framework to other theories as well as its limitations. I then situate my work within a larger context on research for promoting cycling. The discussion also offers a reflection in environmental sustainability and HCI, and closes by showing the limitations of the work presented in this thesis.

Chapter 9 presents the conclusions and summarizes the contribution of this thesis.

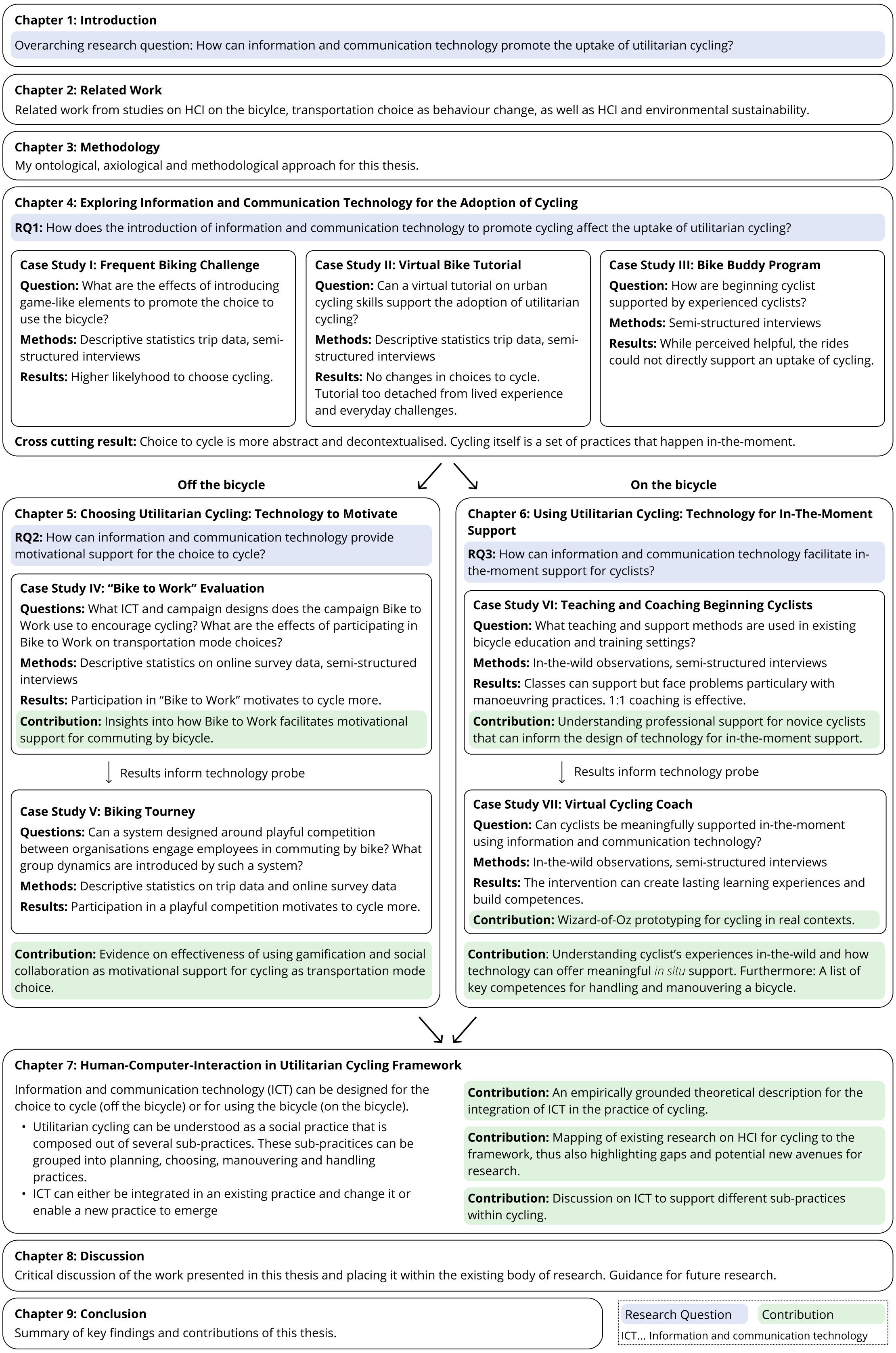


Figure 1.1: Thesis outline

CHAPTER 2

Related Work

In this chapter I shine light on related research – particularly in the field of HCI – regarding cycling. An emphasis is thereby put on information and communication technology (ICT) relevant for cycling as an everyday, utilitarian transportation practice. Furthermore, I highlight work that is relevant for understanding the interplay between ICT and the adoption of cycling, that is, the integration of cycling into one's everyday routines.

2.1 Cycling as Social Practice

As cycling is such a common everyday activity, we have an intermediate familiarity with it. This can derive from personal experiences of using the bicycle as a mode of transportation, from memories of learning to ride a bicycle and using it as a child, or from it being a leisure time activity, either for casual rides on weekends or more sportive uses, such as mountain biking or road cycling. The latter often come with their own set of meanings and material components, e.g., in the form of specialised cycling clothing and accessories. Finally, a source of familiarity is observation. So even those who never cycle themselves have a grasp of cycling. Hence, we are quick to retrieve associations with cycling which might depend on our own personal experience with it: From it being a playful to sportive leisure activity, to more practical aspects such as travel time, cost of ownership, carrying capabilities, to an outside view of cycling as something "others" do.

In this thesis I am investigating the practice of utilitarian cycling. I define utilitarian cycling as *using the bicycle to derive utility such as getting to a desired location or transporting goods*. It is typically integrated into one's everyday routines, such as commuting to work, transporting one's children, or running errands. Utilitarian cycling differs from cycling as as leisure time activity, e.g., a ride together with family on a weekend as a way to explore an area without sportive ambitions. It also differs from sportive cycling, e.g., road cycling or mountain biking, which emphasises physical exercise, training and competition. But rather than viewing utilitarian cycling as a mundane, simple, and "just how things are" activity, I view cycling as an everyday social practice (Shove, Pantzar, and Watson 2012; Reckwitz 2002; Kuutti and Bannon 2014). As a practice, it has emerged and changed over centuries. This puts an emphasis on the "doing", understanding routinised practices that are widely shared throughout society, contextualised by being bound to time and space, and strongly interconnected with other practices. In Social Practice Theory, Reckwitz (2002) defines a practice as a "routinized type of behaviour which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge". In this perspective, human action is understood as the performance of a practice, a contextualised doing, that does not derive from within an individual, but exists through the repeated performances by many. Practices emerge, change, and can cease to exist over time, and can in a strong use of the theory be viewed as a unit of inquiry itself, with individual behaviour being a performance or an instantiation of the practice. The theoretical lens of social practices shows the range of elements which comprise and converge in practices. Furthermore, a practice approach – quite similar to action- or activity-based descriptions – demands attention to the ways in which practices bundle together in people's lives. This orients our thinking to a more systemic level, by pointing out how particular practices are embedded within each other, e.g., practices of residential living and working are often intertwined with transportation practices, forming a system of practices (Watson 2012). The practice of utilitarian cycling may also overlap with other forms of cycling, e.g. when cycling to work with a deliberate detour on one's road bike to use the commute as training opportunity.

In this thesis I use the flavour of Social Practice Theory proposed by Shove, Pantzar, and Watson (2012). There, social practices are constituted of three elements, which are

- "*materials* – including things, technologies, tangible physical entities, and the stuff of which objects are made;
- *competences* – which encompasses skill, know-how and technique; and
- *meanings* – in which we include symbolic meanings, ideas and aspirations." (Shove, Pantzar, and Watson 2012)

These elements are brought together by an individual in the moment of performing a practice. Spotswood et al. (2015) provide an analysis of cycling for utility in the UK. They empirically show how it differs from other forms of cycling such as casual cycling for leisure, to more sportive forms like mountain biking or road cycling. Utilitarian cycling is – as implied by the term – about the utility of using the bicycle for one's transportation needs. This extends to the material elements of the bike, with bicycles used for utilitarian purposes being designed for comfort, providing carrying options, having integrated lights and being equipped to conform to legal requirements for riding on public roads – something e.g., mountain bikes in Austria, are typically not. Moreover, the material elements involved in utilitarian cycling stretch beyond the bicycle itself: The built environment, particularly the infrastructure used to ride on, but also material things such as bike storing facilities or elements to regulate traffic get integrated into the practice. Lastly, the meanings around utilitarian cycling include practicality and utility. They also include an aspect of environmental awareness, e.g., due to lower emissions of greenhouse gases or particular matter compared to other transportation practices, such as driving a motorised vehicle. Meanings also extend to the social status that is conveyed by transportation choices as well as the status of a cyclist on a street, i.e. being an equal participant vs a hindrance that blocks the road for motorised traffic. Main findings of an analysis by Spotswood et al. (2015) are shown in Figure 2.1.

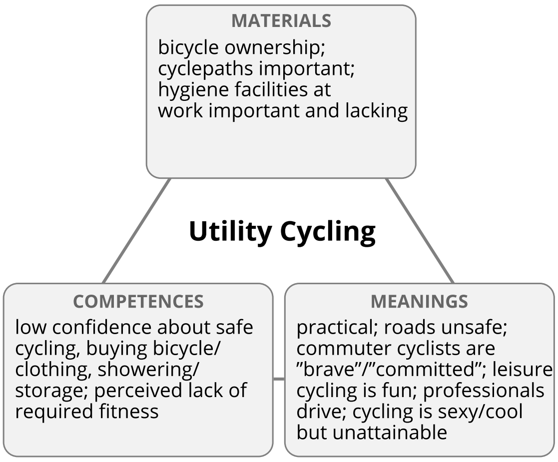


Figure 2.1: Analysis of utility cycling within Shove et al.'s Social Practice Framework. (Spotswood et al. 2015)

For this thesis I am interested in the role of ICT for *individuals* adopting the practice of cycling. Within the case studies presented throughout chapters 4, 5, and 6 I will thus keep the attention towards the individual. For the conceptual framework introduced in Chapter 7 I then connect the findings from across the case studies back to a social practice lens. By that I situate human computer interactions with ICT within the elements that constitute our everyday doings, as it has been done before for other social practices (e.g., Disalvo, Redström, and Watson 2008; Entwistle et al. 2015; Nunes 2015; Ganglbauer, Fitzpatrick, and Comber 2013).

2.2 HCI and Environmental Sustainability

Cycling is a practice that can contribute to environmental sustainability. As for this research on digital technology to support the uptake of cycling, there has also been relevant criticism on such approaches. Strengers (2014) argues that such technology is often implicitly designed for a rational, technically minded, environmentally aware and potentially male person – "resource man" – which does not reflect the reality of everyday life. Therefore, resource consumption should be viewed as embedded in fuzzy everyday life and arising from an interplay of practices. For example, people rarely think about the energy-consuming behaviours in the household in terms of the energy they consume, but rather as the "purpose" they fulfill (Brynjarsdottir et al. 2012). Similarly, utilitarian cycling should not be viewed as a means of reducing one's carbon footprint, but as sharing an understanding of it being an effective mode of transportation, and having the material elements and competencies to incorporate that into one's daily routines.

A shift away from the rational sovereign consumer has already occurred in consumption research (Shove, Pantzar, and Watson 2012; Warde 2005) as well as HCI research (Entwistle et al. 2015; Kuutti and Bannon 2014). Schwartz et al. (2013) conducted a phenomenological inquiry pointing out how feedback technologies can be designed to support the practice of making energy consumption accountable. Kuijer, A. d. Jong, and Eijk (2013) used a social practice lens to investigate designs that act as material elements allowing new practices of bodily hygiene to emerge. Similarly, practices around thermal comfort have been explored (Kuijer and A. d. Jong 2012). Ganglbauer, Fitzpatrick, and Güldenpfennig (2015) used this theoretical frame to guide their work on food waste practices and technology designs to reduce waste. Design considerations for creating technology supporting self-care of Parkinson's patients was explored by Nunes (2015). To inform ICT designs, Hasselqvist, Hesselgren, and Bogdan (2016) applied a social practice lens to the usage patterns of car driving and how other modes of transportation could be used as substituting practices. They highlight how car use is intertwined in many other practices and identified opportunities for designers of interactive technologies to substitute it. However, this practice based approach has not yet been used for cycling.

2.3 HCI on the Bicycle

Supporting cyclists through navigational guidance is a common theme in HCI research. Therein, a focus has been on the effectiveness of different interaction modalities. Waard et al. (2017) compared four modalities: a paper map, a map displayed on a smartphone, auditory route guidance and a dedicated system with flashing lights for supporting navigation. They found that turn-by-turn guidance with auditory and, to a lesser extend, visual guidance on the digital map, were preferred. Modes of interactions such as tactile feedback for navigation support have been studied in detail (Bial et al. 2012; Poppinga, Pielot, and Boll 2009; Steltenpohl and Bouwer 2013; Tsukada and Yasumura 2004). Navigational guidance has also been studied for child cyclists by Matviienko, Ananthanarayan, El Ali, et al. (2019) using and comparing visual, auditory and vibrotactile navigation cues. Rittenbruch et al. (2020) presented a computing toolkit for rapid exploration and co-design of such interfaces that are used on the bicycle. The use of projections from the bicycle has been explored for both navigation by projecting a map (Dancu, Franjcic, and Fjeld 2014) and to project turn signals on the street (Dancu, Vechev, et al. 2015). On-bicycle navigation has also been studied with the goal of supporting excursions and the exploration of unfamiliar environments by bicycle (Pielot et al. 2012; Poppinga, Pielot, and Boll 2009).

Providing feedback on action on a bike has been studied in multiple ways: Context aware sensing has been used to help cyclists regulate their speed to cross all traffic lights on green, taking into account both the context and actions of the cyclist (Andres et al. 2019). Okugawa et al. (2015) explored training systems that provide immediate feedback on the pedalling cadence in sports-oriented cycling. Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. (2018) also compared the effectiveness of visual, auditory or vibrotactile cues for hazard warnings for children while cycling. Work by Heinovski et al. (2019) explored how such warnings could be realised in real-world settings using vehicular ad-hoc network technologies. While these studies offer valuable insights into the interactions with technology on the bicycle, there remains a gap on understanding the technology's role for the adoption of cycling as regular activity.

2.4 Transportation Research and Cycling

Transportation research has been mostly concerned with cycling from an economic and engineering perspective. The body of research that extends beyond the ideas of rational agents does provide meaningful insights for the work at hand. Dill and McNeil (2016) explored motivating factors, barriers, and preferences for different bicycle facility types for both cyclist and potential cyclists. They describe the barriers for the group of "interested but concerned" to ride for utilitarian transportation needs. Those barriers include not having a bicycle, needing a vehicle for work, routes being too long to ride by bicycle, too few bike lanes, and traffic. Fraser and Lock (2011) provide a meta-review on the associations between the built environment and the rate of cycling. While short trip distance is one factor associated with bike use, there are many other factors as well: A short distance to a cycle path, having dedicated cycle routes, safe routes to schools, population density, mixed land use, separation from traffic and the recreational quality of the route (i.e. green space).

Commuting is a prime example for utilitarian cycling. The subsequent list is based on Heinen, Wee, and Maat (2010) and provides an overview on findings related to bicycle commuting:

- Increased **trip distances** result in less cycling (Parkin, Ryley, and T. Jones 2007; Stinson and Bhat 2004; Dickinson et al. 2003).
- More **cycling infrastructure** results in more cycling (Barnes, Thompson, and Krizek 2006; Pucher and Buehler 2006).
- **Cycling infrastructure** which separates cyclists from other traffic is preferred by cyclists (Hunt and Abraham 2006; Stinson and Bhat 2005; Stinson and Bhat 2003; Taylor and Mahmassani 1996).

- **Network layout** has no significant effects on the choice to cycle (Moudon et al. 2005; Zacharias 2005).
- Higher **density** correlates with higher levels of cycling. Proximity to urban centres corresponds with an increased likelihood to cycle (Parkin, Wardman, and Page 2007; Guo, Bhat, and Copperman 2007; Dill and Voros 2007; Zahran et al. 2008).

Transportation research shows a positive relation between the available dedicated bicycle infrastructure – such as a network of separated bike lanes – and the degree to which citizens choose cycling (L. Pearson et al. 2022; Fishman 2016; Pucher and Buehler 2008). In other terms, it is the ease of use that the built infrastructure if being designed for which reduces the level of proficiency needed to cycle. Previous studies show that the experiential quality of a route plays a role in navigation and people trade maximum directness for lower stress (Stinson and Bhat 2005). Route choices can also differ depending on the level of cycling experience, with inexperienced cyclists being more sensitive to factors related to separation from automobiles, whereas experienced cyclists are more likely to choose routes with shorter travel times (Stinson and Bhat 2005; Haworth and Schramm 2011). This relation between a navigation support system and the cyclist's experience of built infrastructure has not been studied so far in HCI research, and context awareness in this area of transportation and mobile HCI has been almost exclusively limited to geolocation data.

Changes of transportation mode choices towards commuting by bike have been studied by Gatersleben and Appleton (2007). They applied the transtheoretical model of behavior change (Prochaska and Diclemente 1986; Prochaska 2015). In line with this theoretical underpinning, they identify groups within their study sample which can be linked to the stages "precontemplation", "contemplation", "prepared for action", "action" and "maintenance". It remains open for discussion if these groups also represent a process of adoption. Gatersleben and Appleton (2007) do point out that different systems and forms of support are wanted by those groups. In line with research shown above, those are a closer travel distance, and better and safer facilities for cycling. In addition, commitments for work and family are reported as barriers to adopting bike commuting.

2.5 HCI and Transportation Mode Choices

The guiding research question in this thesis is how ICT can promote the uptake of utilitarian cycling. "Uptake" thereby includes learning to use the bicycle, start to use it for utility purposes, or using it more often. Any of those scenarios includes choices, e.g., the choice to learn cycling or the choice to use the bicycle on a given day. Over the last decades, a view of mental processing and decision making known as dual-process theories gained traction. Within this strain of cognitive psychological theories, two forms of human mental processes are distinguished: On the one hand, there are fast processes, guided by heuristics, and based learned cues. They can be emotional, such as fear, anger, desire or enthusiasm. On the other hand, there are slow processes, rationally weighting in, which require substantial amounts of mental effort and capacity (Kahneman 2011; Slovic et al. 2005). It can thus be useful to view choices, such as the choices related to cycling, as either automated and habitual (e.g., Verplanken and Aarts 1999) or reflective and effortful (e.g., Froehlich, Dillahunt, et al. 2009).

The emphasis of change of choices – such as in the uptake of cycling – is a guiding theme in behaviour change research. Across research disciplines, such research investigates the effectiveness of techniques to change behaviour. Michie et al. (2013) presented an extensive taxonomy covering 93 such techniques. Each of those includes an understanding of what constitutes behaviour and how processes of adopting an activity can occur. For example, the strategy "feedback on outcome(s) of behaviour" is described as "Monitor and provide feedback on the outcome of performance of the behaviour", which could e.g., be done by monitoring a person's weight, physical activity, and diet. Another example is the strategy of avoiding exposure to cues that can trigger behaviours. Within HCI research, Fogg (2003)'s work on persuasive technology offered an early model for the interplay of ICT and human choices. It described a space, where given a set of motivation and ability, a trigger could then cause a certain behaviour or choice. Froehlich, Findlater, and J. Landay (2010) and Oinas-Kukkonen and Harjumaa (2008) presented behaviour change techniques as frameworks to inform technology designs. Similarly to Michie et al. (2013), those are lists of possible techniques, which by the use of technology include self-monitoring, feedback, social comparison, goal-setting and rewards.

With this backdrop, previous HCI research has contributed in the field of active transportation by studying technology for implementing such behavior change techniques. ICT was often the means to sensing and revealing information about a user's transportation behavior, with the goal to promote active transportation. Froehlich, Dillahunt, et al. (2009) developed a mobile phone application that semi-automatically sensed and revealed information about transportation choices. In combination with a personal ambient display, the app engaged users with the goal of increasing green transportation choices (e.g., walking, biking, public transport). Gabrielli and Maimone (2013) examined the effect of a mobile app on supporting ecological transport choices by citizens of an urban area. They observed an overall increase of sustainable transport choices and a higher environmental awareness among participants. However, the study design had a small sample size (n=8) and hence these findings represent indications. Flüchter, Wortmann, and Fleisch (2014) found a positive impact of social normative feedback on e-bike commuting. Supporting eco-friendly choices such as cycling is done with information and guidance using journey planning services (R. Kazhamiakin et al. 2015; Raman Kazhamiakin et al. 2021; Magliocchetti et al. 2012; Semanjski et al. 2016).

Using ICT to introduce game-like elements to environmentally sustainable mobility choices is another theme found in related research. Technology artefacts designed as "sustainability challenges" have e.g., been studied by Broll et al. (2012), Gabrielli, Maimone, et al. (2013), and Wernbacher et al. (2015). The behavior change technique of using social comparison has also been instantiated, e.g., with leader boards, and has been studied by R. Kazhamiakin et al. (2015), Magliocchetti et al. (2012), Wernbacher et al. (2015), or Gabrielli and Maimone (2013). Another approach is self-monitoring, often enabled through graphical, statistical representations of reported or logged mobility behaviour (e.g., found in Broll et al. 2012; Gabrielli, Maimone, et al. 2013; Semanjski et al. 2016; Wernbacher et al. 2015). Klecha and Gianni (2018) provided a recent review outlining commonly used approaches for research and design of applications for promoting sustainable urban mobility behaviour.

My studies, particularly in Chapter 4 and Chapter 5, follow similar approaches. However, in case studies IV and V, larger sample sizes than in the previous studies help to provide credibility to the results. Furthermore, I therein also investigate the larger context of the technology intervention, i.e. the role the physical and social environment have for the choice to use the bicycle. In Chapter 6 I then move to the aspect of competencies and thus the ability to perform the practice of cycling. I thus work with two different theoretical guides, one emphasising the choice to cycle, the other the performance of social practices of cycling. Chapter 7 then provides a framework to bridge those two perspectives.

2.6 Chapter Summary

As ICT is becoming an ever more pervasive part of our everyday life, it will also likely become just another layer added to the cycling experience. It is thereby important to note that cyclists already do interact with technology. Besides balancing, steering and overall controlling the bicycle, they do use roads, bike lanes, traffic lights, street markings etc. to get around. All this is just part of a larger, complex context, consisting of other traffic participants using the same spaces on foot, car, bicycles, trucks or other means of transport. To perform the social practice of utilitarian cycling, cyclists need to exercise skillful control over their bicycle while applying knowledge and being exposed to a variety of – potentially dangerous – situations (Pooley et al. 2013; Telfer et al. 2006). Information and communication technology is something that gets added to this setting and should thus be understood in a contextualised way.

There is still little research concerned with how technology can add to the practice of cycling. The studies on supporting the uptake of utilitarian cycling shown above were mostly small in their scale. They also center around a behaviour change perspective. There are only few studies so far on the experiences of cyclists while using digital technology that promotes the uptake of utilitarian cycling in real-world scenarios. Transportation research points out that the context of cycling – particularly in urban environments – is critical for the choice to cycle. This has also been rarely addressed in HCI research on utilitarian cycling. After the subsequent chapter on methodology, I will therefore present seven case studies within chapters 4, 5 and 6 to address this gap.

CHAPTER 3

Methodology

In this chapter, I first outline the ontological and epistemological stance of my research. I then explain my axiological approach and personal values. Furthermore, I provide the reasoning for choosing methods and describe how I used them to collect, analyse and interpret data. I also highlight the applied quality criteria.

The work presented in this thesis was conducted as part of the research project "Persuasive Urban Mobility". It has been a research collaboration between the Media Lab at the Massachusetts Institute of Technology (M.I.T.)[1] and the AIT Austrian Institute of Technology[2]. The project was funded by the Austrian Institute of Technology. My main collaborators were Alexandra Millonig, Agnis Stibe, Stefan Seer, and Ryan C.C. Chin. The project's initial goal was to apply persuasive technologies to urban mobility to facilitate behaviour change of individuals towards environmentally sustainable modes of urban transportation, particularly cycling. While the studies from the project are the foundation for this PhD thesis, I move beyond the project's scope and draw attention to the complexities involved in using information and communication technology to support cyclists. Grounded in that perspective, I present the Human-Computer-Interaction in Utilitarian Cycling Framework, that connects to the existing body of research on HCI and cycling. The introductions of the following empirical chapters outline who was involved in the presented work to distinguish between my work and work done with my colleagues. Furthermore, I use the pronouns "we" and "I" in the text to delineate work I did alone from work done together with my colleagues.

[1] https://www.media.mit.edu/
[2] https://www.ait.ac.at/

3.1 Ontological Approach

The work in this thesis captures research that spanned several years and represents a constant learning process. At the same time, my methodological positioning found a stronger foothold. I found myself initially struggling with the tension between a (post-)positivistic and a constructivist philosophy of science. The former, with its goal of producing generalisable, objective knowledge, seems intuitively more "scientific" than the latter, which aims to offer an understanding that is situated in a broad context, and always subjective (Guba and Lincoln 1994). I attribute much of this struggle to the broad scope of my research topic. On the one hand, there are many aspects that suit a post-positivistic ontology: Examples range from interactions with a device on a bike, to balancing, accelerating and steering a bicycle, and interacting within traffic. One could ask questions about mental workload, distraction, safety distances, turning radiuses or lines of sight. On the other hand, when attention is put on the meaning of using the bicycle, such as personal values and social norms that this is communicating, or the political forces shaping infrastructure, or trying to understand the experiences of cyclists, a constructivistic lens provides a way of creating rich, situated knowledge. This tension is typical in the field of HCI. Harrison, Tatar, and Sengers (2007) argued that there "are three paradigms of HCI: Human-Factors, Classical Cognitivism/Information Processing Based and the Third/Phenomenologically-Situated Paradigm. Each of these paradigms represents a world-view and encompasses a set of practices and expectations for the value and contribution of research. Each contributes to HCI, but in different ways." HCI as a research field has been and is still grappling with tension from these different paradigms (Frauenberger 2019). Hence, my own struggle to initially situate my work is representative of the larger field wherein this thesis is situated.

My ontological stance is pragmatic: I understand the world as real while knowing that this understanding is an unavoidable mental construction. I have no reason to doubt that much of our world – particularly within the natural sciences – can be described in theory, which is supported by hypothesis testing. Such research lends itself to deductive reasoning, moving from theories and the general to more specific instances, often testing specific hypotheses and aiming for confirmation or rejection of original theories, applying philosophical concepts such as falsification. This approach is essential to the post-positivistic research paradigm, where there is a reality that can be objectively described and explained with "probably true" knowledge. However, when moving into the social, the human side of the everyday as objects of research, I get confronted with a complexity that limits attempts to objectively understand an outside reality, particularly when this reality is a shared mental construction that exists in meanings, culture, and values, which indirectly also affect most human-made material objects. Human nature, from the individual to the society is seemingly too fuzzy, too complex, too dependent on too many aspects to be only understood or described with the same philosophical confidence as an objectively observable reality.

My research in this thesis is therefore situated in constructivistic ontology. By accepting that there is no one universal reality, but those realities exist in the form of multiple, in-tangible mental constructions, that are socially and experientially based, local and specific but often partially shared among many. The seeds of this constructivism–interpretivism can be found in Kant's "Critique of Pure Reason" (Kant 1787). Hamilton (1994) describes Kant's thinking of human perception as something, deriving "not only from evidence of the senses but also from the mental apparatus that serves to organise the incoming sense impressions" and that "human claims about nature cannot be independent of inside-the-head processes of the knowing subject". This ontological view accepts that what is there to be understood is subjective. That there can be no objective explanation, but rather informed and sophisticated constructions (Guba and Lincoln 1994) that "reality is constructed by the actor (e.g., research participant)" (Ponterotto 2005).

In this thesis, I explore human choices and experiences in a local, context-dependent and specific manner by interpreting them and ultimately creating a conceptual framework that captures my findings. The constructivist's position on what is there to be known is thereby logically consistent. Furthermore, this philosophical stance sits well with the theoretical positioning, particularly understanding "cycling" or "using interactive technology" as social practices. As discussed in the previous chapter, these can even be understood as entities on their own that are mostly independent on the individuals performing them (Shove, Pantzar, and Watson 2012; Reckwitz 2002). This also is inspired by ideas of the late Wittgenstein (1968), that meaning in language is created in its use, and thus not something objective that is independent of the humans who use it. The same thought guides this ontological view.

3.2 Epistemological Approach

As the epistemological question asks for the relationship between the knower or would-be knower, and that what can be known (Guba and Lincoln 1994), my pragmatic ontology guides me towards a constructivist's stance for the work in this thesis. In this thesis, I emphasise the importance of context, situatedness, and understanding an individual's experiences of cycling (Haraway 1988; Frauenberger 2019). This necessitates acknowledging the social, cultural, and physical context of my study participants, me and my colleagues (Harrison, Sengers, and Tatar 2011).

My research process is characterised by inductive reasoning, moving from specific observations to broader generalisations and theory. It is driven by empirical data to form a more general understanding of the designed technologies and reconstruct their use in context and its consequences. The process of generating this understanding is also guided by the body of related work, making explicit claims on the structure and processes involved in human thinking and action.

My epistemological position also includes that I, as a researcher, cannot be independent or objective to the subject of my research, as this work and I are spatially, temporarily, economically and politically interconnected. Knowledge is thus created in a transactional way from the interactions of me, as the investigator, with the respondents (Guba and Lincoln 1994). In line with my ontological position this knowledge does not describe one objectively observable reality, but multiple ways to look and understand, to construct and make sense of empirical data. For the sake of comprehension, however, terms such as "real" and "context" are used with their common meaning, while accepting that the "real-ness" and the "context" that technologies are getting used are in the end shared constructions and shared realities between me and my research participants.[3]

3.3 Axiological and Personal Approach

The inter-subjective, transactional nature of this research calls for a reflection on the implied values. I was motivated to do my research by concerns about today's material and socio-economic structures, which already negatively impact society and will do so even more on future generations. My research goal of informing the design of information and communication technology that supports utilitarian cycling represents a way to contribute to improvements in everyday living and environmental sustainability.

This personal background and set of values impose important challenges to me, the researcher: I am a passionate participant in the field that I am studying while I also act as a facilitator of a multi-voice, inter-subjective reconstruction of it (Guba and Lincoln 1994).Therefore, it was important to me as the researcher to accept and value statements – independent of their commensurability with my personal values. Thus, while I carry my ideals, I value others' ideas on shaping our environment and how we as members of societies live together.

3.4 Methodological Approach

Based on those ontological, epistemological and axiological premises, this section highlights the methods that have been applied for this PhD research and the criteria used to ensure the quality of the process and findings.

3.4.1 Research Quality Criteria

There are competing claims as to what counts as good quality work. Discussions of quality in social research began from concepts such as validity and reliability, which derived within the quantitative (post)-positivistic research paradigm (Seale 1999). For the constructivist approach taken in this thesis, Guba and Lincoln (1994) define a set of five criteria to be met by qualitative research:

1. Credibility (paralleling external validity): Across the presented case studies I show and clearly explain the used methods, provide evidence for the arguments made and critically discuss the findings and their limitations to show how my contributions

[3] There is an exciting discussion moving forward within the HCI community on epistemological approaches (e.g., Harrison, Sengers, and Tatar 2011) and work such as Frauenberger (2019) on *Entanglement HCI* provides great inspiration on philosophical issues in the field of HCI research.

are trustworthy research.

2. Transferability (paralleling external validity): The knowledge gained through my research can be transferred to other contexts. This is even highlighted within this thesis itself as the different case studies include similar themes to show transferability, e.g., case studies I, IV and V explored the use of social- and game-like interventions in different contexts, or Case Study VII included two study waves using different prototypes and different regions (U.S. and Austria).

3. Dependability (paralleling reliability): By describing the region, participants, and setup of the interventions that have been studied I account for the context within my research occurred.

4. Confirmability (paralleling neutrality or objectivity): The knowledge offered by this thesis comes with a description of the technology designs and the study procedures to enable others to confirm and expand on the presented knowledge.

5. Authenticity, which revolves around multiple aspects of accountability according to Seale (1999):

   - Fairness: By critically reflecting on the findings in each chapter and in the discussion I represent a range of different realities.
   - Ontological authenticity: I help develop a more sophisticated understanding of the research area, i.e. the connection between HCI and cycling. This is most particularly done with the conceptual framework presented in Chapter 7.
   - Educative authenticity: According to Seale (1999), this aspect is about research helping members appreciate the viewpoints of people other than themselves. This aspect was not used to inform the case studies.
   - Catalytic and tactical authenticity: My research stimulated and empowered action by helping some participants to cycle. The findings should also empower fellow researchers in their work.

Auditing is viewed as a key to a methodologically self-critical account of how the research was done. For my PhD research, having constant contact with my supervisor, academic colleagues and reviewers, both in the process of researching and presenting results, was the main way for auditing. A critical outside view both helped to stay aware of limitations and blind spots.

3.4.2 Used Methods

Table 3.1 shows the methods used in the case studies. The subsequent subsections present how I applied those methods for the research presented in this thesis. Methodological details that only apply to individual case studies are left out in this chapter and are described in the sections which report those case studies.

Table 3.1: Methods used for this PhD thesis

Case Study	Method	Participants
I – Frequent Biking Challenge	Quantitative analysis of daily trip data and transportation mode choices	12
	Pre-intervention online survey	10
	Post-intervention online survey	10
	Semi-structured qualitative interviews	2
II – Virtual Bike Tutorial	Quantitative analysis of daily trip data and transportation mode choices	11
	Pre-intervention online survey	8
	Post-intervention online survey	8
	Semi-structured qualitative interviews	2
	Semi-structured qualitative expert interviews	1
III – Bike Buddy Program	Semi-structured qualitative interviews	11
	Pre-intervention online survey	9
	Post-intervention online survey	9
IV – Bike to Work	Post-intervention online survey	498
	Semi-structured qualitative interviews	9
V – Biking Tourney	Post-intervention online survey	127
VI – Teaching and Coaching Beginning Cyclists	Semi-structured qualitative expert interviews	3
	Participatory observation	12
VII – Virtual Cycling Coach	Semi-structured qualitative interviews	25
	Participatory observation	25
	Semi-structured follow-up interviews after three months	15

The use of different methods was chosen to allow for a broader set of evidence, thus increasing the credibility of the results. From multiple fine-grained personal in-depth interviews to large scale online-surveys, the acquired knowledge is grounded in both specific and detail-oriented realities as well as general insights at community or even population level. Such an across-method triangulation within the same research endeavour allows for the combination of those types of insights. Or, more generally, the "[...] rationale for this strategy is that the flaws of one method are often the strengths of another; and by combining methods, observers can achieve the best of each while overcoming their unique deficiencies" (Denzin 2009).

Representing a range of different realities is key to the quality of research, as suggested by the fairness argument of authenticity. The across-method triangulation helps to create data that covers larger sets of people and therefore helps to see different realities and situate the qualitative findings within a larger context. For example, when describing a process of increased bicycle use during participation in the campaign Bike to Work (Case Study IV), the quantitative survey data allows us to capture the numbers of participants living through that process, e.g., by estimating their share among all participants. By that, the presented findings are more authentic and offer different ways of knowing about a subject.

Beyond learning from my study participants, they also ultimately guided my research and design. In particular, after the initial three case studies, the subsequent studies, as well as the technology interventions used within them, were informed by my understanding of the choices and experiences of my study participants. For example, the everyday situations described by my interviewees provide a detailed understanding of the context any technology may be used in. Another example was the chance to cycle together with my study participants. By letting me observe and interview them in situ, I could empathise with their experiences on the bicycle in real-world situations. That, in turn, informed systems such as the Virtual Cycling Coach used in the case studies.

The empirical studies in this thesis have all been conducted in real-world contexts. In comparison to lab studies, they thus emphasise ontological authenticity and contribute to a better understanding of the context of utilitarian cycling. Furthermore, it enabled me to learn about the needs and experiences of cyclists within real contexts.

3.4.3 Data Analysis

Thematic Analysis of Qualitative Data

For the analysis of qualitative data, I relied on "reflexive thematic analysis" according to Braun and Clarke (2019) and Braun and Clarke (2006). It was used for identifying, analysing, and reporting patterns – or themes – within data. This form of thematic analysis can be driven by theoretical or analytic interest of the researcher and in this research both interests were of concern. Whereas qualitative data is often used for providing a rich description on more general levels, thematic analysis is geared towards a detailed description of some aspect of the data. For the research presented in this thesis this approach was chosen to focus analytical attention on everyday practices and their relation to personal mobility and the role of the designed artifacts for those.

In the analysis, I used a semantic approach, where themes are identified within the explicit meanings of the data. Following Braun and Clarke (2019), the analytic process involved a progression from the description, where data is organised along patterns within it, to summarising, where the semantic content is explained, to interpretation, where there is theorising about the relevance of patterns and their meanings. In general, I followed these steps for the process of semantic thematic analysis (Braun and Clarke 2019; Braun and Clarke 2006):

1. **Familiarising with the data:** This happened by immersing myself in the collected data through transcribing recorded interviews, re-reading them or listening to the audio recordings. Memory protocols were important for re-visiting interviews and observations without audio-visual recordings. There was also a process of immersion for quantitative data by going through all collected data, delving into answers of single individuals, and reviewing answers of certain groups.

2. **Generating initial codes:** These initial codes were generated and assigned to snippets within the data. Those snippets ranged from one word within a transcript to whole paragraphs. The codes captured semantic or latent content. The former consisted of "explicit or surface meanings of the data" (Braun and Clarke 2006), whereas the latter already involved interpretation and meaning-making. Furthermore, some codes were theory-driven, i.e. the codes were based on theoretically described elements. Table 3.2 includes examples of such initial codes created during the analysis of Case Study III (Bike Buddy Program). However, to not lose the flexibility granted by a qualitative research approach, features of the data that could not be captured by those codes prompted the creation of new codes that were then assigned. By that, the analysis remained open to generate unexpected themes.

3. **Generating themes:** In this phase, the analysis process moved from single codes to themes, which are more overarching and relational. I hereby began to find a relationship between codes and themes that are grounded in the data. Furthermore, levels of themes were identified in this step. (Braun and Clarke 2006) These levels, which I found across the case studies, also informed the dimensions in the conceptual framework to structure the small practices that compose cycling. While some initial codes were the basis for main themes, others did merely form smaller sub-themes, and I discarded some that did not lead to a well supported theme eventually. As for the quantitative data, this phase involved a process of filtering and grouping within the data to also identify similar themes.

4. **Reviewing themes:** In this phase, previously detected themes could turn out as insufficient, e.g., because the coded data did not provide enough consistent support for them. Some themes were too big or lacked precision, making it necessary

Table 3.2: Examples for initial codes from Case Study III

Code	Description	Type
"it makes me nervous"	Statements by interviewees on negative emotions while cycling	semantic
"competence:repairs"	Statements about the skills needed for bicycle maintenance and repair	theory-driven
"real bikers"	Statements about one's self image and perception of other cyclists	latent
"talk while riding together"	Interviewees describing how they interacted or talked during the bike buddy bicycle rides	semantic
"dealing with infrastructure"	Statements about tactics to cope with issues around cycling infrastructure	thematic

to break them down into multiple themes. In contrast, other themes were too indifferent, resulting in a better outcome when they were combined with each other. I judged themes along the guidance that they should be internally homogenous and externally heterogeneous (Patton 2005). Connections between themes from qualitative and quantitative data were made in this phase whenever a method triangulation was used.

5. **Defining and naming themes:** In this phase the essence of each theme was defined and re-defined so that it clearly represents an aspect of the data. Part of this process was to identify possible hierarchies of themes that result in having sub-themes. The data was coded either by using the software QDAminer, or by hand on printed transcripts. The emerging themes were visualised using mind-maps created by software (Mindmapper), or clusters of post-it notes on large tables or whiteboards (see Figure 3.1).

6. **Producing the report:** This last phase contained the write-up of the produced insights and results. While it was the last step, the need to form coherent arguments in writing which were well supported by data led to continuous refinements of my analysis in the process. One part of this work is the choice of data extracts, e.g., direct quotes from interviews, to demonstrate the themes' prevalence and make a theme more comprehensible to a reader.

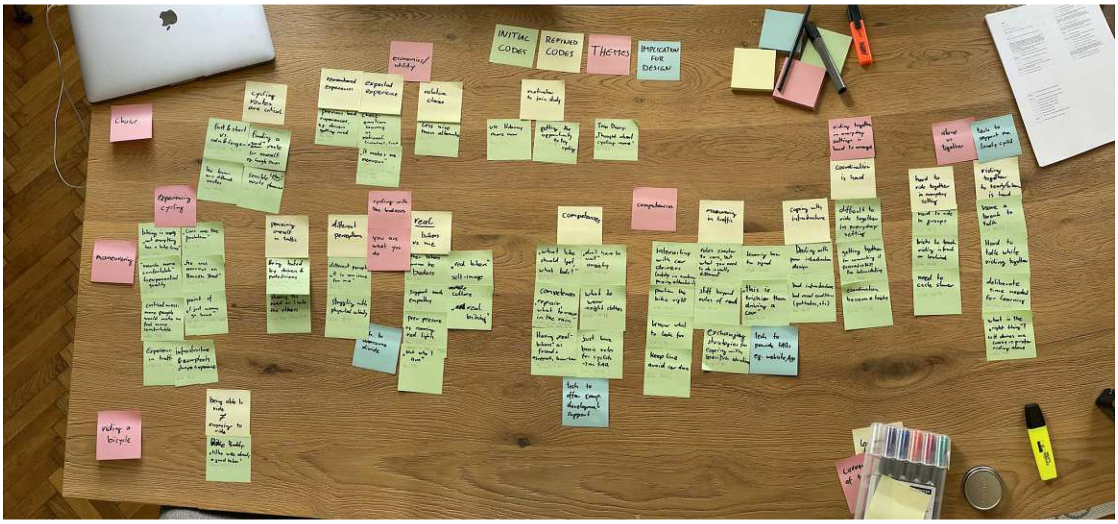


Figure 3.1: Initial codes and the clusters around emerging themes. Example taken from the analysis for Case Study III.

Descriptive Statistical Analysis

Quantitative data that was collected through standardised questions in online and in-person surveys were used for descriptive statistical analysis. Online surveys were conducted using Surveymonkey. Data was analysed, and the graphics were created using both RStudio and Microsoft Excel. Whereas Guba and Lincoln (1994) argue that such statistical analytical approaches fall into a rather post-positivistic research paradigm, I hereby take a more pragmatic stance. Those numerical methods to capture and analyse data are means to structure and simplify observations and findings.

3.4.4 Describing Causal Relationships

Part of my research was to find, understand and show causal relationships. I thereby follow a definition introduced by Wittgenstein (1968), who drew the analogy that causality can be understood like family resemblance. If we think of a family, we can see the resemblance of individual members. Facial features, expressions, hair colours, skin tones and the like might be similar. While we can neither take one particular feature nor a set of them, with a pre-defined if-then clause, to exactly say that the individuals resemble a family, seeing them together, we know that they look enough alike to likely be a family. In line with that concept, I view causation in a pluralistic way: Some but not all cases of causation involve temporal priority or constant conjunction. Some but not all cases involve contiguity or have to make a difference. None of these features can be said to be either necessary or sufficient for causation. However, causal cases will possess enough of these features so that we can recognise them as causal (Mumford and Anjum 2013).

The methods described are used to empirically understand the role information and communication technology can have for adopting cycling as a practice for everyday mobility. Therefore, I observed, interviewed and surveyed study participants to obtain such an understanding. The methods used for this thesis allow for the creation of such an understanding based on subjective, individually constructed realities. With that come constructed causal relationships. They can already be constructed by the research participant in her statements or through my analysis. They can also exist on a societal level as a shared meaning. An example is the role of time and cost for transportation choices, which are so interwoven into the discourse of everyday mobility, that viewing them as causes has become ubiquitous.

Everyday practices are the result of many aspects, e.g., habit, symbolic meanings, cost, convenience, time. At the time of investigation, those tend to collapse into the actions and verbal responses made by research participants. The dual-process-theories introduced in the previous chapter can also have implications in that regard. During inquiry, study participants are likely thinking reflectively. The causal relationships described at this moment might be relevant but could also be incomplete or leave other causes underexposed. This view got more support by recent studies involving MRI scans (Soon et al. 2008), which highlighted that choices are often made in regions of our brains not associated with conscious thought, only to be later "communicated" to our more aware brain regions. Research has also shown that we tend to rationalise our actions *ex-post*. Past decisions can lead to changes in attitudes to preserve a state of internal consistency and justify one's actions (Festinger 1962; Festinger 1964; J. Stone and Cooper 2001).[4] As this idea was brought to transportation research, Tertoolen, Kreveld, and Verstraten (1998) report changes in attitudes and tendencies to excuse oneself when discrepancies between attitudes and choices, e.g., environmental awareness and driving instead of using public transport, are made salient. Socially shared and accepted concepts such as "saving time", "being efficient", or "being necessary" can thus be both causal reasons, or after-the-fact justifications, especially as personal transportation goes beyond the utilitarian and has symbolic and affective functions (Steg 2005).

The assertion of causal relationships thus needs careful consideration, and, in line with my philosophical stance, I am aware that these are mental constructions rather than a description of an objective, observable reality. I will get back to these boundaries of describing causal relationships in my research within the section Limitations in chapter 8.

3.5 Ethics

An ethical problem arises from the dangers inherent to cycling. As with all modes of transportation, there is a chance of having an accident. Prior to conducting the case studies I, II, III, V and VII, a formal ethical review by the Committee on the Use of Humans as Experimental Subjects (COUHES) at the Massachusetts Institute of Technology (MIT) has been completed. As an example, the documentation of this

[4] For a recent synthesis of explanations see J. Stone and Cooper (2001).

COUHES review and the consent form of the case study on the Virtual Cycling Coach is included in the appendix to Chapter 6. Case studies IV and VI followed the same guidelines but did not undergo a review process by a committee as TU Wien had no such process. All participants had to give informed consent before participating in the studies.

The consent form provided to the participants typically included this information:

- **Participation and withdrawal:** Details on participation, e.g., beginning, duration and end of the study, as well as the information that a participant can withdraw at any time.
- **Purpose of the study:** Participants have been informed up front about the purpose of the study they participated in. They had several days to consider their participation. Participants could withdraw at any time from the study.
- **Procedures:** The activities a participant was supposed to do during the study.
- **Potential risks and discomforts:** Participants were informed that cycling itself has risks. Due to the chance of having an accident while cycling, participants in studies that included them riding a bicycle were advised to ride safely along the roads, wear helmets, avoid distractions, and place caution and safety above all else.
- **Potential benefits:** Personal benefits gained from participating in the study.
- **Payment for participation:** The participants involved in the case studies did not receive any payment for their participation. This was clearly stated in the consent form.
- **Details on confidentiality:** How we would handle data and personally identifiable information.
- **Identification of investigators:** The participants have been clearly informed about my and my colleagues identity, our role in the project and our professional affiliation. They were also provided with contact details, typically my or my colleagues' work email address.

Information that was obtained in connection with the case studies that can be personally identified did remain confidential. I asked for additional consent from individual participants when disclosing such data, e.g., by using non-anonymised photos or videos within this thesis, its connected publications or on academic conferences.

Ethical considerations specific to individual case studies are outlined in their respective methods section.

3.6 Summary

In this chapter, I outlined that I follow a pragmatic ontological stance. For the work in this thesis, which emphasises technology's role in utilitarian cycling, I investigate deeply situated, contextual and social phenomena using a constructivistic philosophical lens. I then provided details on the choice and execution of the methods used for the subsequent case studies.

CHAPTER 4

Exploring Information and Communication Technology for the Adoption of Cycling

Information and communication technology is becoming ever more pervasive in our everyday lives. From smartphones to smartwatches, smart household appliances, smart cities to smart vehicles, computing gets ever more integrated into the things we use and the activities we do. As shown in the literature review, there is little research on the interplay between ICT for adopting cycling into one's everyday routines.

This chapter empirically explores three approaches of supporting the adoption of cycling through ICT. The guiding research question thereby is *RQ1: How does the introduction of information and communication technology to promote cycling affect the uptake of utilitarian cycling?* I present three case studies to answer that research question: First, a game-like approach, the Case Study I (Frequent Biking Challenge), which introduced game mechanics to help build and keep motivation for regular cycling. I thereby focus on choices of individuals. Second, the Case Study II (Virtual Bike Tutorial), an application for training utilitarian cycling skills in a safe environment. I thereby emphasise the role of competences in utilitarian cycling and introduce an ICT intervention that happens in a safe setting of a personal computer, rather than during riding a bicycle. Third, the Case Study III (Bike Buddy Program), an intervention to explore the use of a matching algorithm to connect people willing to cycle more with experienced cyclists. While this case study is still centered around competence development and support of cyclists, the intervention takes place in real world contexts, which enabled us to learn about the challenges that come with it.

Insights from across these case studies help to inform the design of information and communication technology that promotes the uptake of cycling. In the three studies, I show motivational aspects for transportation mode choices and experiences of cyclists while adopting cycling. Furthermore, I describe the challenges people encounter when adopting cycling and highlight the limitations of ICT-based interventions.

The case studies presented in this chapter were part of a research project between the Media Lab at the Massachusetts Institute of Technology (M.I.T.) and the AIT Austrian Institute of Technology. The project aim was to study the use of persuasive technologies to increase the use of low-energy transportation modes within cities. Alexandra Millonig, Agnis Stibe, Ryan C.C. Chin, Stefan Seer, Katja Schechtner, and Kent Larson have been involved in this project. Geraldine Fitzpatrick provided generous support and guidance for my academic development, writing and thinking. Within this chapter, I use the pronoun "we" to refer to activities where my colleagues contributed substantially to the work presented in this chapter. The findings from the case studies have been published at the conference Persuasive Technology 2015.[1] *However, this chapter is largely based on me revisiting the original studies from a perspective that is more critical on behaviour change agendas. I thereby emphasise how insights from these studies informed my later work and the Human-Computer-Interaction in Utilitarian Cycling Framework presented in Chapter 7.*

4.1 Methods

The three case studies presented in this chapter were conducted in parallel in Cambridge and Boston, Massachusetts, United States over the period of four weeks in October 2014. Prior to conducting them, a formal ethical review by the Committee on the Use of Humans as Experimental Subjects (COUHES) at the Massachusetts Institute of Technology (MIT) was completed.

4.1.1 Study Participants

The three case studies were conducted at the same time as one overall research study. Processes such as recruitment of participants, ethical review, collection of surveys and collection of trip data was handled across the three case studies. Study participants were recruited primarily through mailing lists at the Massachusetts Institute of Technology (MIT). In total, 85 people initially agreed to participate in our research. Out of those, 11 withdrew before the case studies started. A further 19 participants already cycled regularly, i.e. more than three times a week, and were already experienced cyclists and therefore asked to participate in the study by becoming a bike buddy within CS III (Bike Buddy Program). Six of them eventually participated by doing so. The remaining 55 participants with less cycling experience consisted of 27 women and 28 men. They were randomly assigned to one of three case studies or a control group. Participants in the

[1] The publication related to this is: *Wunsch, M., Stibe, A., Millonig, A., Seer, S., Dai, C., Schechtner, K., and Chin, R.C.C. 2015. What Makes You Bike? Exploring Persuasive Strategies to Encourage Low-Energy Mobility. In: Persuasive Technology. Ed. by Thomas MacTavish and Santosh Basapur. Lecture Notes in Computer Science. Springer International Publishing, pp. 53–64.*

control group were asked the same questions and received similar benefits, but were not part of any further intervention.

Due to the recruitment procedure participants were primarily part of the MIT community consisting of students and otherwise affiliated persons. The study sample is hence not representative of a broader population. Furthermore, the sample most likely exhibits self-selection bias, as people with a motivation to bike more were more likely to join.

Out of all participants, 33 had no access to a bike and were provided with a one-month subscription to the local bike-sharing scheme Hubway. The Hubway subscription was provided through a coupon at the beginning of the study, which was used to register for a Hubway key. Those participants had access by the second week of the studies. Furthermore, 24 participants did not own helmets and were provided with one.

Group sizes in the studies were n=12 for Case Study I (Frequent Biking Challenge), n=11 for Case Study II (Virtual Bike Tutorial), n=11 for Case Study III (Bike Buddy Program) and n=10 for the control group. 44 participants reported their daily trips continuously over the period of four weeks. The sample of 44 participants that continually reported their trip data consisted of 22 women and 22 men.

Table 4.1: Study participants

Case study	**Participants n (female)**	**Complete mode choice reports**	**Complete questionnaires**	**Interviews**
I: Frequent Biking Challenge	13 (7)	12	10	2
II: Virtual Bike Tutorial	15 (8)	11	8	2
III: Bike Buddy: Mentees	13 (5)	11	9	5
III: Bike Buddy: Mentors	6 (3)	-	-	6
Control	14(9)	10	10	2
Total	61(32)	44	37	17

4.1.2 Data Collection

Participants reported their daily trips including the trip purpose and used mode of transportation. I developed a trip diary as a web application – My Trip Diary – shown in Figure 4.1. As a research team, we designed this application in a way that enabled our participants to easily report their trips of the day and the used mode of transport. For this, we omitted the collection of any specifics per trip, such as points of departure, points of arrival, trip time or trip distance. My Trip Diary allowed participants to seamlessly enter the trips with just a few taps. It included a calendar view to navigate through the days, a help section and a statistics graphic where users could see how their trips were distributed into different modes of transportation. A settings section allowed the users to set a time for the daily reminders, create custom trip purposes and set their time zone. The My Trip Diary application also provided a brief tutorial after the first login, and automatic reminders via email were sent to participants in case they did not report their trips for a day. Collected data was sent to a web server and stored in a relational database.

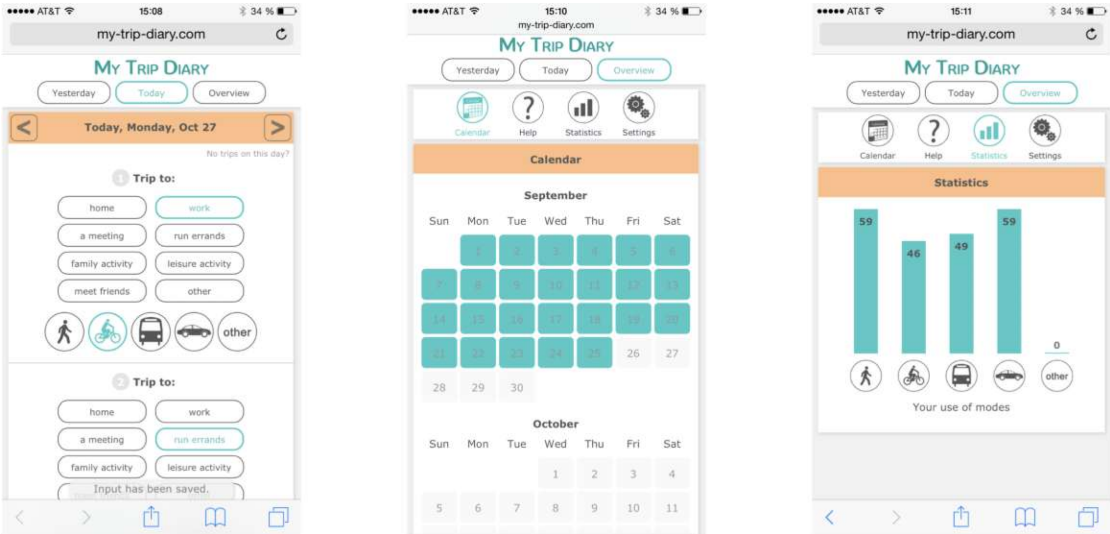


Figure 4.1: Trip Diary web application: daily trips (left), calendar view (centre) and statistics (right)

Online questionnaires were used at the beginning and end of the study period. Those included open questions and survey items regarding the cycling experience that were also used to capture perceived risk and perceived safety of cycling. Semi-structured interviews were conducted with participants from each study group as shown in Table 4.1. Questionnaires and interview guidelines that have been used are included in the appendix to this chapter.

4.1.3 Data Analysis

Unstructured data has been obtained through open questions in the online questionnaires and the interviews after the study period. The recorded interview data was partially transcribed, that is parts of likely relevance for this research were transcribed word by word, other parts – such as unrelated stories or introductions – have been summed up in the transcripts. A thematic analysis was carried out together with two colleagues[2]. Post-it walls and spreadsheets were used to support the process of analysis and deduction. Written information from surveys was not transcribed, otherwise the procedure followed the description provided in the previous chapter.

[2] Agnis Stibe and Alexandra Millonig

The reported trip data offered quantitative insights into daily mobility choices. Descriptive statistics were used to present and analyse this data. With the reported trip data, a daily likelihood of using the bicycle was calculated. This represents the average share of days a bicycle was used for at least one trip by participants within a given period. This trip data is used for capturing changes in choices. However, due to the small sample sizes, a test for statistical significance is intentionally omitted here. Even though some changes would be statistically significant, this significance could potentially give a wrong impression of a valid or reliable result – which again given the small sample sizes of these initial three case studies – is not justifiable. Those statistics should rather serve to provide an overview on transportation mode choices, which represents an additional data point to understand the effects the interventions have. Yet another data source are standardised questionnaires on perceived safety and perceived risk of cycling. The appendix to Chapter 4 includes these questionnaires.

4.2 Case Study I: Frequent Biking Challenge

This case study is the first to explore the interplay of information and communication technology and transportation mode choices. Particularly the effect on choosing the bicycle as a mode of transport, or starting to do so more regularly, is of interest here. Adopting a new activity is often a winding road, requiring a person's attention, motivation and having the opportunity to do so. Even then, there often remains an intention behaviour gap, i.e. all the reasons and factors outside our control that prevent or make it too difficult to actually follow through with one's intention. Regarding physical activity, a meta-study showed that more than a third of us struggle with bridging this gap and turn intentions into action (Rhodes and Bruijn 2013). As for information and communication technology this has led to plenty of research and many products that provide support for the intended choices. Examples are wearable devices with fitness tracking capabilities that encourage their users to reach certain levels of activity e.g., by measuring their heart rates and step counts.

A common theme in designing such artefacts is to use "gamification", that is "the use of game design elements in non-game contexts" (Deterding et al. 2011). This can be done by adding game interface design patterns, such as goals, badges, leader-boards or levels. It can also be done by adding game models and mechanics such as challenges, triggering one's curiosity, or adding various constraints to an activity. Technology with its capability to be situated and personal, e.g., by using software on smartphones, provides the opportunity to bring such designs to the field of daily transportation mode choices. The specific research question motivating this study hence was: *What are the effects of introducing game-like elements to promote the adoption of utilitarian cycling?* For this case study, an intervention called the "Frequent Biking Challenge" was designed and developed to probe into that idea.

4.2.1 Intervention Design

The "Frequent Biking Challenge" was designed around encouraging participants to cycle regularly. By participating in the study, people were challenged to use their bicycles on a regular basis. I implemented the system as a mobile-optimised web application shown in Figure 4.2 (left). The login was realised as a single-sign-on together with the My Trip Diary application used to capture the daily journeys.

The game mechanics involved that a user received points based on the number of reported bike trips. Those points unlocked different levels, each having a distinct title, illustration and an exploratory slogan. For example, when achieving 10 points one received the status "Experienced Biker" which had the slogan: "With experience comes wisdom. You know how to ride the streets." Participants also received a virtual badge when they achieved a level (see Figure 4.2 left). Early in the study, all participants were invited to jointly reach a total number of points. After this collective goal was fulfilled, a more common game mechanic of social comparison was used: The number of individual bike rides was shown and compared to the average rides of all participants and to the current front-runner's number of rides (see Figure 4.2 right). The "compare yourself" design element allowed participants to compare the number of their bike rides to the average of bike rides and the best participant within the group. The email updates furthermore included a leader-board, showing one's own rank based on the achieved points in comparison to the other participants of the group. It was visualised with a podium for the first three places, followed by a list of the other ranks. This enabled participants to compare their performance with the best and the average performance in the group to activate competition-based motivation (Shapiro and Wilk 1965).

To provide study participants with information about their performance in the challenge, they regularly received emails. These emails should also serve as a reminder for cycling (Figure 4.2 right). Emails were chosen as they are likely to be regularly read as opposed to a website or a mobile app providing the same information and push notifications could not be implemented with the used systems. The emails were sent in the evening, so they could be read before choosing a mode of transport the next day. The regular email updates also contained a set of messages tailored to each participant, such as daily weather forecasts or entertaining facts. The purpose of these was to keep the sent emails useful and engaging for the participants. Additionally, the emails provided motivational facts about biking and suggestions on when to use a bike. During the first week, participants received email updates on a daily basis; after that, the frequency was reduced to three to four times per week. The emails were sent in the evenings to be mentally present in a potential time of planning the next day.

4.2.2 Methods

Within the first 12 days, the 13 participants only reported their daily trips using the My Trip Diary application. This pre-intervention phase offered data on the current daily transportation routines. On the 13th day the "Frequent Biking Challenge" was introduced,

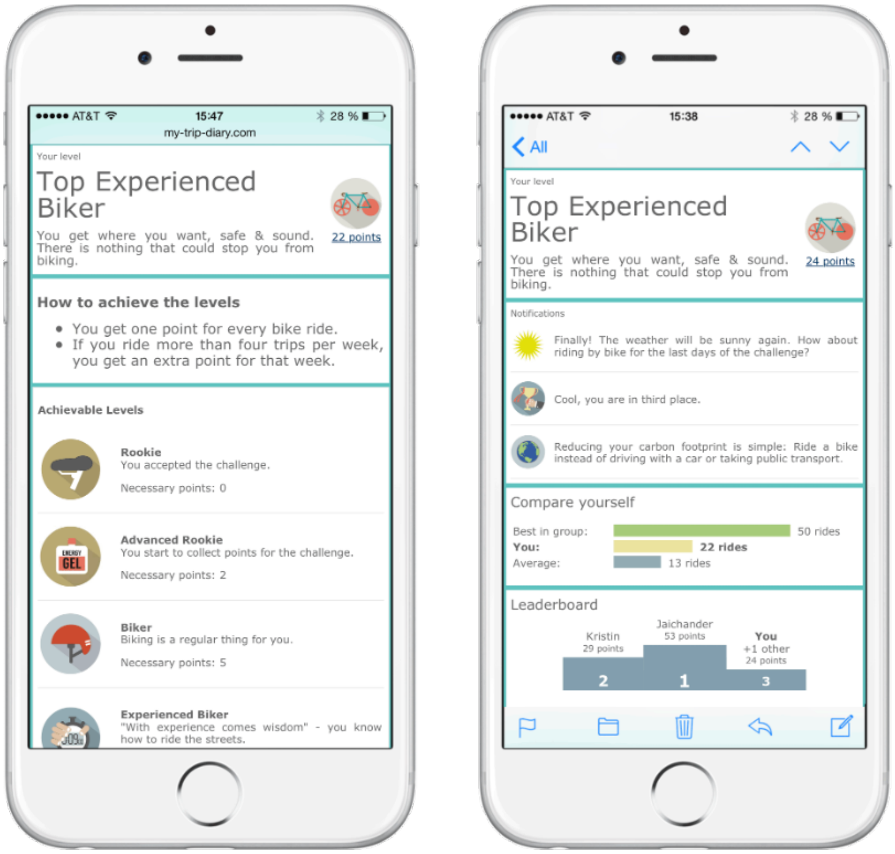


Figure 4.2: "Frequent Biking Challenge" levels (left) and information updates (right)

which lasted a total of 17 days. Afterwards, study participants had to complete the post-intervention online survey within the following two weeks. Participants of this study group furthermore received another online survey with open questions about their transportation routines nine months after the intervention ended. In addition to the open questions from the online surveys, we conducted semi-structured qualitative interviews with two study participants. The interviews were audio-recorded, fully transcribed and analysed using thematic analysis described in the previous chapter. Participants were furthermore contacted 9 months past the initial intervention and asked to answer an open question follow-up questionnaire.

The daily likelihood of using the bicycle was calculated for the pre-intervention phase, i.e. before the Frequent Biking Challenge started, and the during-intervention phase. The values shown for the control group were calculated for the same time period. Given the small sample size, these likelihoods are shown both on a per participant basis and as averages across the group. The former allows for a more qualitative assessment of the distribution of the changes, the latter for easier comparison with the control group.

Table 4.2: Messages used in the Frequent Biking Challenge (examples)

Condition	Messages
Good weather forecasted	"Tomorrow's weather will be okay for biking."
Only 1-2 rides missing to achieve next status (Status)	"With just one more point you will achieve Experienced Biker status."
If in second place	"Great, you are in second place."
One week before Halloween	"Get your Halloween costume! Bike to Garment District (200 Broadway). There is even a Hubway station at One Kendall Square. Get directions"
None	"Reducing your carbon footprint is simple: Ride a bike instead of driving with a car or taking public transport."

4.2.3 Results

The analysis of the daily transportation choices at an individual level showed increases in the share of days a bicycle was used. Figure 4.3 shows the changes for each participant indicating that seven out of the 12 participants were more likely to use the bicycle in the time period after the Frequent Biking Challenge started. None of the participants was less likely to use the bicycle after the start of the intervention. Notably, four participants neither chose the bicycle before nor after the start of the Frequent Biking Challenge.

On average, the likelihood of using the bicycle was 17% before and 41% during the Frequent Biking Challenge. Within the control group, the likelihood in the time periods increased from 23% to 34% (Figure 4.4).

Within the collected qualitative data a theme of raised awareness due to using the My Trip Diary application was present. Due to regularly reporting mobility choices, participants became aware of habitual, automated choices and potentially questioned those existing habits. As the purpose of the study was on cycling, this reflective thinking was potentially directed to that activity. One participant put it like this: "Having constant reminders to think about what I was doing and the fact that after some time I had had enough casual conversations and I managed to solve one of the bigger bike barriers that I had." (p61) However, the same might have been the case for the participants assigned to the control group.

Most of the included game elements were based on a social setting, e.g., the leader-board that showed the participants their points and rank among others. This had little meaning as the other participants were unknown and for some, the role of such social features would have been more meaningful if they had known other participants.

The provision of access to shared bikes was potentially an important driver for enabling an increased use of the bicycle. This will be further analysed later in this chapter within the cross-cutting results. Hence, afterwards a need to renew the subscription or buy a

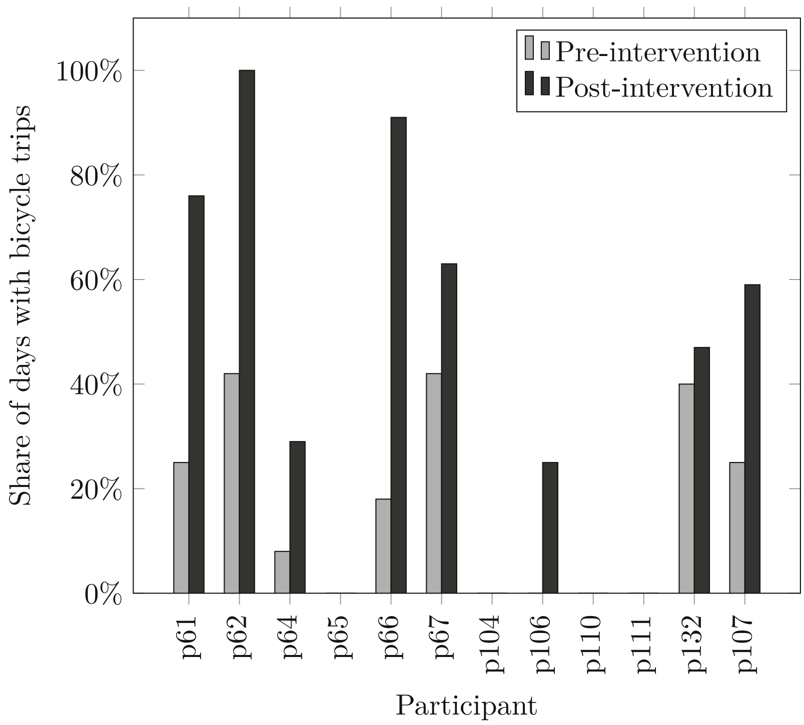


Figure 4.3: Individual daily likelihood of using the bicycle

bicycle to have access to a bicycle arose. For some this was a suitable solution allowing them to continue cycling, e.g., one participant reporting in the follow-up survey: "I renewed the Hubway membership subscription you gave me and have been biking about the same ever since" (p62). However, others gained too little value from the use of a bike-sharing scheme and were not inclined to invest in an owned bicycle: "I have since transitioned back to mostly walking. I feel that bike-share programs are not worth the cost, and unfortunately also lack a good place to store a personal bike." (p66)

Within the follow-up interviews, we also found that cold weather prevented some people from sustaining the habit of regular bicycle use. As the study was done in October the cold winter months made cycling potentially less attractive, which resulted in choosing other modes of transport. One participant put it like this: "I got out of the habit of daily biking over the winter, and now commute primarily on foot. I bike maybe once a week to run an errand or attend church, more or less what I was doing before the survey started." (p61)

Further findings from the qualitative interviews are presented within Section 4.5 Cross-Cutting Results.

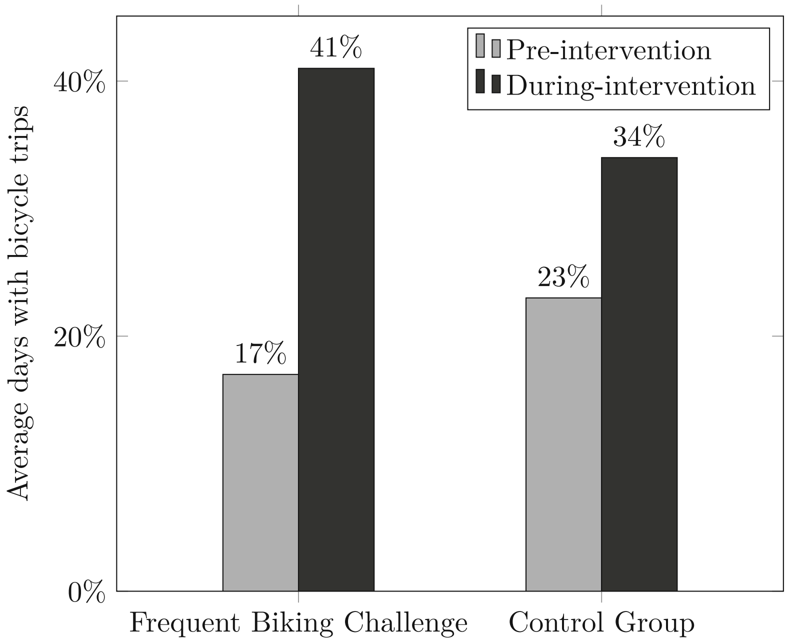


Figure 4.4: Average daily likelihood of using the bicycle: Frequent Biking Challenge group compared to control group

4.2.4 Discussion

This case study asked for the effects of introducing game-like elements to promote the adoption of utilitarian cycling. The results indicate that there is a connection between participating in the Frequent Biking Challenge and the choices of using the bicycle. This form of technology can potentially help users to start cycling or cycle more. These findings are in line with Kazhamiakin et al. (2015; 2021), who also found an increase in bicycle usage using gamification elements without an existing social setting. They also are consistent with the findings from Jylhä et al. (2013) on motivating users to choose more sustainable means of transport with a system that offers actionable mobility challenges.

Methodological limitations of this case study come from its initial study design that has been centred around capturing everyday transportation choices. Given the small sample size, these findings are initial pointers to the effects of participating in such an intervention. The collected qualitative data across all participants was limited to answers to open survey questions and the in-person interviews. The findings from this qualitative data did not offer evidence supporting the effects shown in the reported trip data.

Overall, details on the underlying processes for such changes in transportation choices could not be uncovered thus far. The usefulness of social features was doubted by the interviewees in this study, as e.g., leader-boards without underlying personal social settings were seen as non-engaging.

To tackle these open questions, the case studies narrowing in on the game-like approaches presented in Chapter 5 are larger in scale and set up to provide further insights into the role technology interventions can have on the choice to cycle.

4.3 Case Study II: Virtual Bike Tutorial

Competencies – which encompass skill, know-how and technique – are essential for adopting the practice of cycling. Within the conceptual framework presented in Chapter 7, these competencies are present in the three types of practices that compose cycling. First, handling practices which involve skills such as being able to balance the bicycle, starting to ride and accelerating from a standstill, steering or braking. Second, manoeuvring practices that incorporate competencies for navigating within the built (cycling) infrastructure, interacting with other traffic participants or following traffic laws. Third, planning practices, where competencies can range from knowledge of possible routes and the ability to plan them to getting access to a bicycle either through owning one or knowing how to use a bike-sharing scheme. In this case study, I initially explored the use of ICT to teach cycling competencies, with an emphasis on skills needed in denser, urban areas. The research question for this case study was: *Can a virtual tutorial on urban cycling skills promote the adoption of utilitarian cycling?*

4.3.1 Design

To answer the research question, we designed the "Virtual Bike Tutorial". It was an interactive training on a personal computer about best practices for urban cycling . It consisted of two parts: First, the instruction that included explanations of key skills for safely riding within complex urban contexts; Second, a training where different scenarios are shown and users need to decide how to react.

The initial design idea was to offer a computer simulation of utilitarian cycling. This simulation would need to reflect the complex situations and interactions encountered by cyclists, such as riding next to parked cars, riding along other cyclists, interacting with pedestrians, traffic signs and traffic lights, as well as using different types of built cycling infrastructure such as separated bike lanes, bike lanes on a street, or mixed traffic. However, no such simulation was available at the time this study was conducted and still is not at the time of writing (summer 2021). There has been substantial progress regarding the mechanical setup of a bicycle within a simulator (Hernández–Melgarejo et al. 2020). A dedicated cycling simulator software has been developed in the FIVIS project (Herpers et al. 2010). It was however not available for this study and the available information suggests that it still lacks the level of realism needed to train complex urban cycling skills. Previous research also adopted car driving simulators for creating a cycling simulator (e.g., Matviienko, Ananthanarayan, El Ali, et al. 2019), however, it also lacks the complexity found in everyday cycling situations. Due to this, the Virtual Bike Tutorial was implemented based on video recordings, i.e. videos were used to show the tutorial and the possible actions of a cyclist.

The content of the instruction part focused on actions for safe urban biking. Safety-related information was sourced from guidelines published by city officials from New York City, Boston and Vienna. Furthermore, I conducted an expert interview with an experienced cycling instructor to gain knowledge on how biking in the city can be taught most effectively to novice bikers. The tutorial was centred around encouraging agency about one's action in traffic. This was instantiated with the slogan "anticipate & react". "Anticipate" thereby encompasses actively understanding one's situation and thinking about potential conflicts and situations. This should encourage reflective thinking about oneself within traffic to enable reacting to anticipated events early enough, for example by riding behind the back of a crossing pedestrian or by keeping enough distance to parked cars whose doors could open. This was exemplified using four situations:

- Riding in mixed traffic: A cyclist should anticipate close takeovers by cars and react by taking enough space within the lane to have safety margins.
- Riding close to parked cars: A cyclist should anticipate that car doors can open and react by riding with enough distance or slowing down.
- Pedestrians walk towards the lane one is cycling in: A cyclist should anticipate that the pedestrians might overlook them and react by riding behind them or slowing down.
- Cycling on a bicycle lane that crosses a sidewalk: A cyclist should anticipate that the pedestrians might overlook them and react by riding behind them or slowing down.

Figure 4.5 shows a screenshot taken from the instruction part. Still-images and the provided content for all sections of the Virtual Bike Tutorial are included in the Appendix to Chapter 4.

After the instruction part, participants entered the second part where they should experience the effects of different biking-related decisions in an interactive video training session. The procedure started with a first-person-view video where the participant saw a typical biking scene. The video was then stopped and the participants had to decide on how to continue the ride. The consequences of each possible decision were shown in a subsequent video. The real-life scenarios have been:

- **Approaching an intersection between a bike lane and a sidewalk behind a pedestrian (Figure 4.5).** Slowing down would be the safest action to avoid a conflict or crash.
- **Approaching an intersection for a left-turn.** The right sequence would be to look back, give a hand signal, look back again, then turn left.
- **Riding on a street lane very close to parked cars.** The correct reaction would be to increase one's distance or slow down to avoid hitting opening car doors.

Figure 4.5: Virtual Bike Tutorial: Training section showing a conflict situation with a pedestrian.

4.3.2 Methods

Out of 15 study participants, 11 reported their daily trips using the My Trip Diary application and were provided with the Virtual Bike Tutorial 13 days after the study had started. On average, the Virtual Bike Tutorial was done by the participants between day 13 and day 24, with the average time to complete the tutorial being day 18. Day 18 was also used to compare the level of cycling with the control group. Other than that, the daily likelihood of using the bicycle was calculated similarly to Case Study I. Like in the prior case study, participants could answer open questions in online surveys. We conducted semi-structured qualitative interviews at the end of the study period. However, we conducted those interviews with only two study participants. This was likely because these interviews were voluntary, the interest in the study faded towards its end, and scheduling was difficult due to a busy period in late fall for the participants working or studying at M.I.T. The interviews were audio-recorded, fully transcribed and analysed using thematic analysis described in the previous chapter.

Besides a change in transportation mode choices, changes in perceived self-efficacy due to that intervention were captured. For this, participants had to complete a self-efficacy in biking questionnaire before and after the video training session. Questionnaires and interview guidelines that have been used are included in the Appendix to Chapter 4.

4.3.3 Results

We assumed that doing the tutorial would affect the perceived self-efficacy and perceived safety regarding cycling. As shown in Figure 4.6, perceived safety was slightly lower after doing the Virtual Bike Tutorial, perceived self-efficacy did slightly increase. However, both do not indicate a substantial shift in how participants assessed cycling. As in the previous studies, tests for statistical significance are omitted here as the small sample size lends itself to a more qualitative assessment rather than a test for claims that are valid for a larger population.

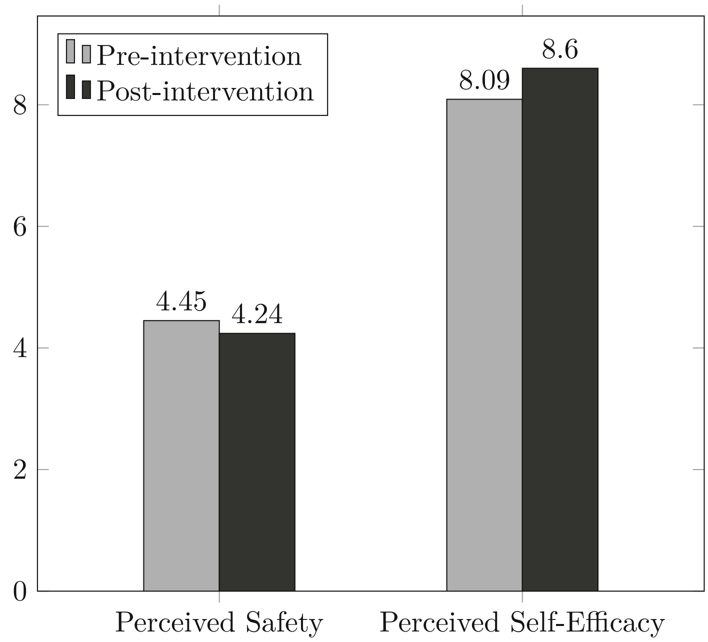


Figure 4.6: Perceived safety and perceived self-efficacy before and after completing the Virtual Bike Tutorial

The analysis of the daily transportation choices at an individual level did not show a clear pattern of increased bicycle use as in the previous case study. Figure 4.7 shows the changes for each participant indicating that four participants were more likely to use the bicycle in the time period after they completed the Virtual Bike Tutorial and two participants (p50 and p75) started to use the bicycle in the time period after they completed the Virtual Bike Tutorial. Two participants were less likely to use the bicycle after the intervention. Neither of two participants did choose the bicycle before or after the tutorial.

On average, the likelihood of using the bicycle was 20% before and 23% after completing the Virtual Bike Tutorial. For the control group, the average day that the tutorial has been taken by the participants was used to calculate the averages. The likelihood there has increased from 27% to 33% (Figure 4.8). This does furthermore indicate no change in the transportation mode choices due to doing the Virtual Bike Tutorial.

The qualitative data from interviews and open questions in surveys point out that the tutorial was too detached from the actual experience of cycling. The videos did include many details to convey the complexity of cycling, including the point of view and the sense of being on a bike. However, the shown situations and tips in the tutorial were

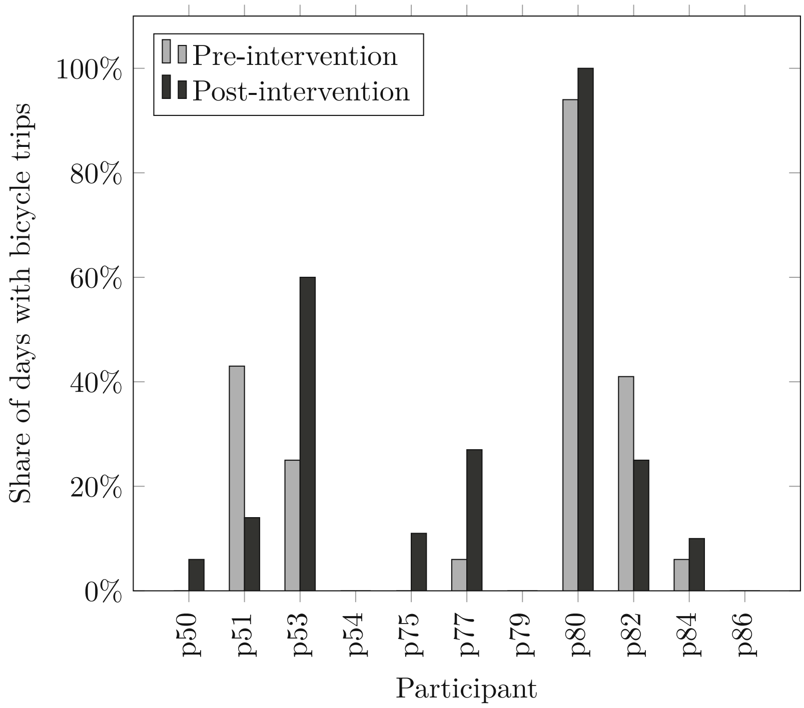


Figure 4.7: Individual daily likelihood of using the bicycle before and after doing the Virtual Bike Tutorial

simple, yet specific to the shown context. Translating those into action on the bike was difficult. One participant described the Virtual Bike Tutorial as "[. . .] less complex than riding situations I have been. I was trying to apply those guidelines to some situations and it did not match." (p84) The training content was insufficient to help with an individual's actual problems. Those included e.g., specific parts of their route, feeling uncomfortable in mixed traffic, or transporting goods.

A minor finding was that the training part was perceived as a quiz. With the design asking for a single choice instead of continuous controlling like in a driving game or simulator, it framed the training as a quiz asking for the right answers. This is likely to result in an even larger detachment between doing the Virtual Bike Tutorial and the actual riding experience.

4.3.4 Discussion

This case study asked if a virtual tutorial on urban cycling skills can promote the adoption of utilitarian cycling. The results do not indicate meaningful changes in neither the perception of cycling nor its use. The training content was likely too abstract and detached from cycling itself, hence not offering help with actual problems and challenges while cycling. This setup might be more effective as an e-learning approach for teaching traffic

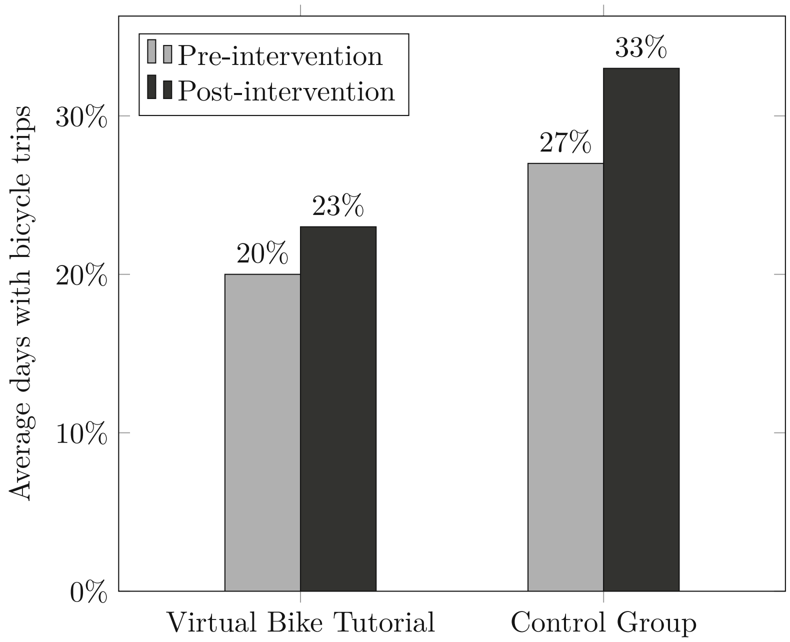


Figure 4.8: Average daily likelihood of using the bicycle: Virtual Bike Tutorial group compared to control group

rules. This implies that technology designs should make the training more contextualised and tailored around the problems laid out in this chapter, to meaningfully support cyclists. I follow up on this implication in Chapter 6.2, where I study the use of a system for in-the-moment and contextual support.

4.4 Case Study III: Bike Buddy Program

The third case study explores the adoption of cycling within everyday context. While it is still concerned with building necessary competencies, I use this case study to explore how those competencies can be gained, and how the adoption of cycling in general, can be supported by other persons. As with most new activities, one can learn alone, receive help

[3] Children in Austria are offered a training for cycling on public streets in primary schools. After completing an associated exam, they are allowed to ride their bicycles on public streets without a supervising person at age 10. Without this exam, children have to be at least 12 years of age to ride alone. In Massachusetts (USA), where this case study was conducted, there is no program coupled to regular schooling of children. Educational programs for all age groups, including children, are however offered by NGOs such as MassBike. `https://www.massbike.org/education` By state law, parents or guardians are responsible for cyclists under the age of 18. `https://www.massbike.org/laws` Other countries have varying other approaches to bicycle education for children. In Germany children in the 3rd or 4th grade of primary school can do a similar training. There are, however, no laws on age for children to cycle alone. `https://www.adac.de/rund-ums-fahrzeug/zweirad/fahrrad-ebike-pedelec/vorschriften-verhalten/kinder-fahrradfahren-strassenverkehr/` England also offers a formal cycle training in primary school (Goodman, Sluijs, and David Ogilvie 2015).

from friends, family, or other acquaintances, and or get support from professionals, e.g., teachers, instructors or coaches. Cycling is often learned at a child's age, and typically within the family. There are also programs that offer bicycle education in schools.[3]

Beyond that, the competencies for everyday utilitarian cycling are likely developed and maintained implicitly, just "by doing it". Over time, this may also result in confidence in riding a bicycle for everyday transportation needs. Implicit learning can also emerge when a novice cyclist gets together with someone more experienced – either by riding together or talking about cycling and sharing information, e.g., on routes, traffic rules, manoeuvring, or gear. Over the last decades, ICT has taken a larger role in this, as shown by practices such as e-learning, online classes and courses, video tutorials, or remote training. There is, however, little research thus far on understanding how processes of mutual support can be facilitated through ICT. This case study aims to gain insights into such processes in such a setting, including a better understanding of the experiences of novice cyclists, which includes persons who have ridden bicycles before but are adopting it now for utilitarian purposes. From the findings I show implications for design, which also informed technology design for competency development in Chapter 6.

For this case study, participants were set up for a one-time "bike buddy ride", i.e. a ride with an experienced cyclist who would provide a mentor-ship. The initial idea guiding this study was to inform a digital platform that uses a matching algorithm to connect people to provide support to beginner cyclists. The precondition was that study participants knew how to ride a bike but did not do it regularly for utilitarian purposes, being "interested but concerned" (Dill and McNeil 2016) regarding cycling. The guiding research question for this case study has been: *How do novice cyclists experience being supported by other cyclists?* The findings from this study have implications for design that inform the subsequent chapters.

4.4.1 Methods

To gain insights into the experience of being supported by other people, we set up the "Bike Buddy Program". It mimics a setting where one would be motivated and supported by a friend or family member. Something that will be further explored in Section 5.1.

The bike mentors were selected if they themselves were experienced cyclists, i.e. typically riding more then three times per week by bicycle, and if they were comfortable with supporting novice cyclists by riding together with them. We created a procedure – as prototype for a possible algorithm – to match the bike mentors and their mentees based on where they lived and what routes they usually took. In total, six bike buddy mentors got to do their ride(s) with another, less experienced cyclist. The bike mentors received instructions for the ride, covering safety aspects and clarifying the goal of showing the participant a safe and enjoyable biking route. They, therefore, were asked to find a suitable route for the planned bike ride and preferably try this route before the ride. They were also requested to set up a meeting point close to the mentee's home. The ride should cover a trip that their mentees needed to cover regularly, e.g., their commute to school or work.

From the participants of the first three case studies, 13 have been assigned to the Bike Buddy Program. Six of those actually did the bike buddy ride as mentees. The reasons for not doing the rides included living too close for cycling to be a benefit, not owning a bicycle and having issues activating the Hubway subscription, or not being able to schedule the ride. Three participants withdrew from the study without providing any details. As the scheduling along time and space was challenging, the bike buddy rides took place in or after the fourth week of the study period, which was two weeks later than planned. As the collection of trip data ended after four weeks, no post-intervention trip data is available. To gain insights into the experiences of the rides, we conducted 11 semi-structured interviews, including all bike mentors and all but one mentee who did the rides. We conducted these interviews within a month after the ride. The interviews were audio-recorded, fully transcribed and analysed using thematic analysis described in the previous chapter.

4.4.2 Results

A typical bike buddy session followed the proposed structure: The matched pair met at a meeting point and usually started with a brief introduction. In cases where bike buddy mentees did not own a bike, the pair then usually walked to the nearest Hubway station to get a rental bike. Either as part of the introduction or immediately before starting to ride, the bike mentors provided tips on cycling in the area. "We talked about different things, things that I wasn't so comfortable with. So like that I asked her, how do you deal with it? And she gave me her feedback. So that was helpful." (p92) Then the pair rode to the destination, with the experienced cyclist riding upfront. The latter reported that they tried to keep an eye on their mentees and adjusted their speed to match. "I stayed in front of her the whole time and frequently looked back, making sure she was within sight and earshot." (p145) Providing feedback or tips verbally while riding was, however, difficult for them, as the distance and noise level did not allow them to talk to each other. Hence, feedback was primarily given in breaks, e.g., at intersections when waiting at red lights or a stop sign. The rides then ended at the agreed-upon destination. Pairs that used a Hubway bicycle rode to the nearest station and returned the bike there. Out of all interviewed pairs, only one pair rode a second time together on their way home. One pair rode not on a regular route, but on a loop in the area where the participant lived to try out cycling there.

Both bike mentees and mentors were overall happy to join such activity. The former saw this study as an opportunity to try out biking or learn something new about biking in their area. "I thought it might be fun to try riding." (p96) The latter were mostly motivated by helping others overcome barriers in using the bicycle more often.

We found multiple themes about the choice to, and experience of, utilitarian cycling. The themes relevant to this case study are outlined in the subsequent subsections. Findings beyond that are part of the next section on Cross-Cutting Results.

"Real Bikers and Me"

We found identity to be an essential aspect of adopting utilitarian cycling. The premise of this case study included that people go through a process of building competencies, and with that confidence, needed for utilitarian cycling. Furthermore, the intervention design intended for more experienced cyclists to support less experienced ones in this process. We found that identity plays a role insofar as people who did not ride their bikes regularly viewed themselves as different from regular cyclists. The novice cyclists ascribed to other, seemingly more routinized cyclists, attributes such as riding faster, in any weather, or dense traffic along with motorised vehicles. The more novice cyclists did not share those. "One day it was gonna be raining and we had the ride planned. And I was like 'Hell no I am not gonna do this in rain'. I am in a different bucket, I guess." (p57) These "different buckets", provide an additional backdrop for understanding the experiences within the bike buddy rides.

On the one hand, the relation to more experienced cyclists was about getting support and learning from each other. "Real bikers" (p156) did offer their knowledge, e.g., with tips for routes, what bike and cycling gear to get, help with repairs, or tools to get. On the other hand, those experienced cyclists could also be intimidating to novices. There was an element of peer pressure emerging from riding along with other cyclists. Typical examples included the speed one was riding at, with inexperienced cyclists often riding slower, thereby "feeling" like an annoyance to other cyclists. Another example was waiting at red lights with no crossing traffic, leading to a moment of peer pressure when other cyclists ran the red light. "Not only am I scared of car traffic, which it terrifying, but also of other bikers that do not respect traffic signals [or] laws, and speed around you on the street, which is almost more scary!" (p96) As one participant referred to cyclists in such situations as being just "badass" (p99)which was something he did not want to be.

Assessing the Bike Buddy Ride

As part of the study design, we provided a certain level of trust as a research group running the study. From a novice cyclist's perspective, however, riding together with an unknown person may have been daunting. She might have been one of the "real cyclists", riding fast or reckless, and not having similar concerns as oneself. "[E]ven the idea of getting together with someone can be intimidating." (p57) This may have also contributed to the high dropout of participants during the study.

The overall assessment of the bike buddy rides themselves ranged from "helpful guidance" to "riding with the badasses". This reflects the different relationships between novice and supposedly "real bikers": One one hand, there was a learning experience, grounded in empathetic support offered by the bike mentor and by being supported while riding, as illustrated by this participant: "I think it's definitely comforting, like a sense of security to have someone around there with you." (p92) On the other hand, such a ride could be intimidating if one's concerns were not addressed or dismissed. For example, one participant's ride with his bike buddy included a section on Beacon Street, a street in Cambridge (MA, USA) with dense traffic and poor road condition due to many potholes. The bike buddy chose this route for its directness and intended to show how it can be ridden safely. The participant, however, had a negative experience, being "stressed out" by the segment of the route. "I liked him, but he also said [. . .] it's not really that big of an issue, but I'm like, well actually I have chosen not to do it like months after months. So, in fact, it is kind of a big issue to me." Tying back into the theme of different identities, the participant concluded that "[w]e were like different types of people [. . .] so we did not have that connection." (p99)

Cycling Competencies

Knowing how to ride a bike is the foundation for utilitarian cycling. For all participants in this case study, skills such as balancing, steering, and riding along with other cyclists in a bike lane have not been an issue. The experiences the less experienced cyclists had were largely shaped by the interactions they had in traffic and how they handled those interactions. The latter has been a topic in the bike buddy rides. It included the road rules and extended to cycling-specific best practices that are often grounded in personal experience with dangerous situations while riding. Empathetic bike mentors were giving advice particularly focused on these interactions in traffic. As one participant put it: "She was great and rode slowly. She gave advice and talked through some of my fears. It was nice." (p96)

Topics raised in the sessions of the pairs included:

- Interacting with traffic and being an equal road user, e.g., with statements such as "don't wait for cars, [. . .] cars will see you. So you don't need to be too anxious about them." (p160)
- Making left turns where you need to cut across in front of others. If this is not possible for you, a way to handle is by pulling to the right and carrying the bike across the street.
- Positioning one's bike to not invite close overtaking maneuvers by motorised vehicles.
- Avoiding opening car doors.
- Poor infrastructure design, e.g., bike lanes that suddenly end and infrastructure quality, e.g., potholes on streets.

The bike mentors have raised these topics. Participants also mentioned that it would be beneficial to have this information handily available. "It might be useful to have like a refresher course or like a booklet and going through what you should be doing as a cyclist." (p92)

Support for Cycling within an Everyday Setting

Integrating the bike buddy rides into the everyday routines has been a difficult endeavour. The plan was to arrange the rides for the second or third week of the study. However, most rides took place in week four or the subsequent days. With the tested pairing process, we first matched a mentee with a bike mentor based on similar regular routes, e.g., their commute. Afterwards, pairs had to find a suitable time to ride together and arrange a date and time for meeting each other. We helped in this process extensively, expecting that this matching of people for the rides could be done by an algorithm in a future larger-scale technology probe.

For the pair, doing these rides together greatly reduced their flexibility. With the set time to ride, one was not in control of when to ride anymore. Thus, a hallmark of private transport – being independent and self-determined – was lost. "[It's a] dilemma in a way that it's great, as long as you want to leave right from my house, right when I want to leave, which is a random time in the morning." (p129) Another difficulty of doing the rides in everyday settings was time constraints. For example, one pair had particular issues, as both renting out and returning the Hubway bicycle was not possible at the planned stations. As the bike mentee had to be at a class at a specific time, the pair's ride ended up being rushed, making it more difficult for the bike mentor to give feedback and provide support.

4.4.3 Discussion

The results show a range of experiences involved in being supported by other cyclists. In this case study, I have shown how identity has been a backdrop for the bike buddy rides. Skinner and Rosen (2016) already remarked that "questions on identity loom large in the social practices of cycling". This also ties in with the element of meaning that is part of the social practice of cycling.

The bike buddy rides needed to be set up as part of this study. This has been a lengthy process and might have contributed to a high dropout rate during the study. Implications for design thereby include: First, if automated in a platform – as it has been a consideration before running the study – a sufficient number of mentors would need to be available at a range of different times and locations. Second, riding together might be easier to integrate as part of a larger systems, e.g., if used as part of bike to work campaigns – as shown in the subsequent chapter. There, the buddy setting could happen with colleagues. The third implication is that providing similar support through technology on the bike might be more feasible. This would make the rides less dependent on meet at a specified time and place, eliminating the need to match and schedule a ride.

This case study did have more withdrawals than the first two case studies. Beyond the issues discussed above, the prospect of cycling with a stranger that is a "real biker" may have been worrisome, or at least not attractive.

In previous studies on one-day initiatives, such as by Crawford (2011) on promoting active transport to school, no apparent effect on subsequent choices to use the bicycle could be shown. The effectiveness of such a paired ride in supporting novice cyclists to try out biking and eventually be confident enough to choose it more regularly still needs to be addressed by future research.

4.5 Cross-Cutting Results

In addition to the insights specific to the three case studies, a set of findings was present across those studies. They shed additional light on phenomena of the adoption of utilitarian cycling. The implications for technology design are discussed in the next section.

4.5.1 Utility of Everyday Cycling

When choosing to cycle, travel time and cost of cycling are mostly always compared to other modes of transport. As for these three case studies, the most common trips reported in this study were getting to work or school and back home. Participants who did not cycle regularly typically walked or used the subway for their everyday trips. For those with shorter walking distances, or a good connection using public transport, the time savings offered by cycling was hence not a motivator for taking it up. "It's a beautiful walk. It's a really nice route anyways. So it's not an issue for me to walk. I really enjoy it." (p92)

Study participants that used the bike-sharing scheme Hubway described that walking to a nearby Hubway station at the point of departure and then walking from a station to one's destination could add substantial time to the overall trip. This often took as long as the time saved by cycling. "For me, if I did use a bike, I would definitely have to own one. Otherwise it's not practical." (p92) Several study participants reported situations with either empty stations at departure, i.e. no bike was available when they got there, or full stations at arrival, i.e. it was not possible to return the bike at a convenient station. In those situations, they then had to walk or ride to another station further away. A mobile app was available to help with this issue and has been actively used by some. However, the overall experience was that Hubway would be not reliable enough for everyday transportation.

Inconveniences also play a role in how attractive cycling is as a transportation option. Having to carry a bike over stairs, a lack of secure storage options, or having a route that requires to ride uphill can make cycling less attractive. Judging the relevance of these inconveniences is thereby subjective. e.g., in one bike buddy ride, the participant described having to cycle uphill on the commute home as a struggle and a large detractor for commuting by bike, while his bike buddy did not see any issue in that.

4.5.2 Bicycle Usage

Across the case studies, changes in bicycle usage could be observed. First, there was a notable difference between participants who already had access to a bike and those who received a free month of access to the local bike-sharing scheme. Figure 4.9 shows how participants that got access to a shared bike had a more substantial increase in bicycle usage. This underlines that the newly granted access enabled them to use the bicycle (more often). Statements collected through the interviews and open survey questions supported that participation in these studies was also seen as a way to try out cycling.

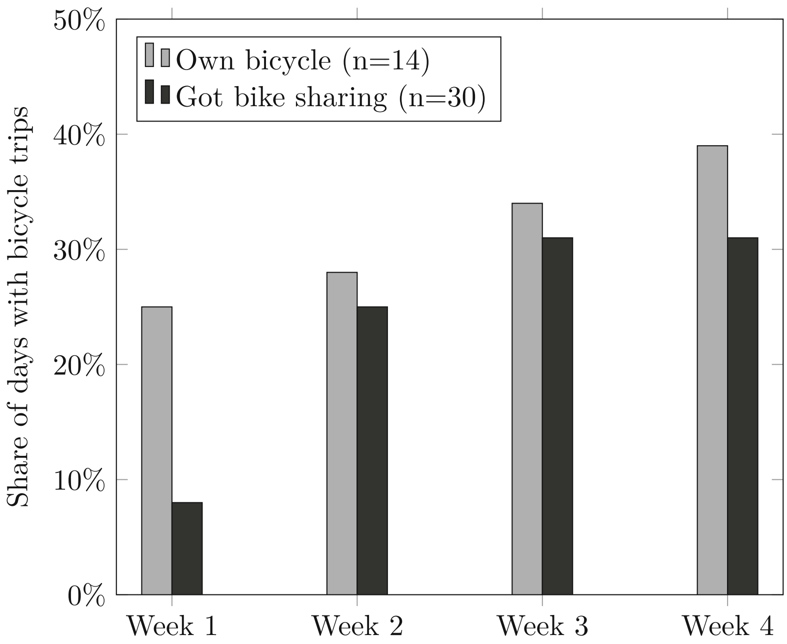


Figure 4.9: Comparison of bicycle usage over time between participants that owned a bicycle and those how received access to the local bike-sharing.

Second, there was a general trend across the case studies to cycle more often as the studies went on. As shown in Figure 4.10, the likelihood to use a bicycle on any given day increased over the study period. The weather was relatively stable during the four weeks of the studies, with rainy days correlating with a lower bicycle usage. The provision of access to the bike-sharing scheme contributed as discussed above. Beyond that, the participation in these studies on cycling might have provoked some form of transformative reflection (Slovák, Frauenberger, and Fitzpatrick 2017; Fleck and Fitzpatrick 2010) due to using the My Trip Diary application or participating in a cycling related study in general. As one participant put it: "I thought about biking more, even though I did not do it much more." (p99)

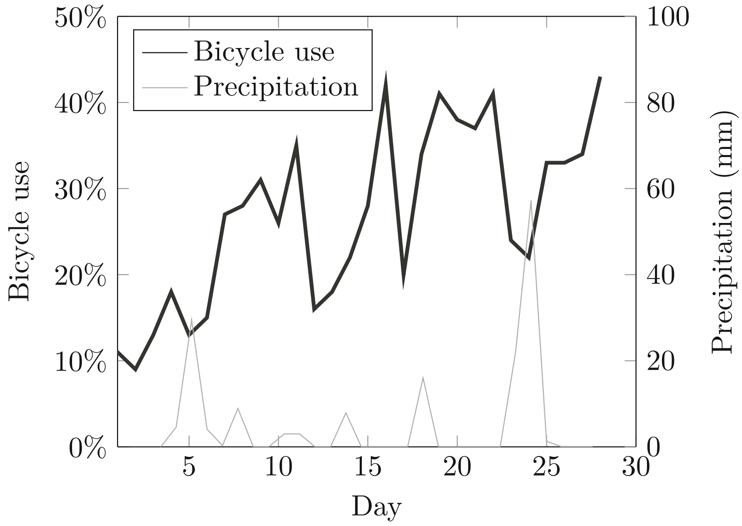


Figure 4.10: Daily average bicycle usage across CS I, II, and III. Secondary axis: daily precipitation.

4.5.3 Experiences in (Urban) Cycling

The study participants often reported negative experiences with cycling. The perceived safety questionnaire offered a nuanced view of some of these experiences during cycling. As shown in Table 4.3, situations in traffic involving motorised vehicles[4] were generally seen as the most likely negative experiences. Compared to those, negative experiences due to situations with other cyclists ("Other cyclists will drive too fast near me.") were deemed less likely. Finally, experiences grounded in own actions, e.g., falling due to a loss of balance or making mistakes, ranked as least likely.

The collected qualitative data also highlighted different aspects of the cycling experience. A strong feeling of being exposed and in danger was a common experience described by participants that did not cycle regularly. The perception of oneself riding the bike also extended to an emotional state of being an annoyance to car drivers and pedestrians. One participant expressed that from the perspective of "a pedestrian or a driver, you hate bikers". (p92)

The route was mentioned as a way to influence the experiential quality of utilitarian cycling. Specifically, within the Greater Boston area, where these case studies were conducted, cycling along the cycling path at Charles River was mentioned as an example of an enjoyable route. Contrasting that are large avenues such as Massachusetts Avenue in Cambridge (MA) with dense traffic and limited to no built infrastructure for cyclists. Riding on such streets and in mixed traffic with many vehicles facilitate the negative

[4]The questionnaire used "cars" instead of motorised vehicles for brevity and clarity. While SUVs, semi-trucks, and other motorised vehicles were thus not explicitly mentioned, the assumption is that the responses for those types of vehicles would be similar.

experiences shown in Table 4.3. There is often tension between different possible routes. On the one hand, there are direct and fast routes. On the other hand, there are routes take longer but offer a more enjoyable ride.

Table 4.3: Experiences in everyday cycling

Statement	**Rating**
Cars will drive too close to me.	4.4
Cars will drive too fast near me.	4.0
I'll be cut off by cars while turning.	3.8
I'll get doored.	3.3
Car drivers will be aggressive towards me.	3.3
Potholes (or circumventing potholes) will cause an accident.	3.3
I'll have an accident in the dark as I am not visible enough.	3.2
I'll be hit by a car because a driver is not paying attention.	3.0
Other bikers will drive too fast near me.	2.7
I'll make a mistake and hurt others or myself.	2.6
I'll hit a pedestrian who gets in my way without paying attention.	2.3
I'll fall off the bike because I can't keep the balance.	1.4

Question: "Think of yourself biking for your usual trips. How do you rate the likelihood of these statements?"
n=65; Scale: 1...very unlikely to 5...very likely

Due to the bike buddy setup, the pair that cycled together could describe the same situation. Compared to their bike mentors, the less experienced cyclists mostly described uncomfortable, challenging moments while cycling. They emphasised this much more, and in a more emotional way, than their bike mentors. Cycling infrastructure was a common theme, with route segments that lack separation from the traffic of motorised being experienced most negatively. Having to ride close to cars was seen as "the problem" (p99), with moments of cars getting "too close", triggering a point where one might be scared and "just want to go home." (p57)

The aforementioned difference in possible routes was also seen in the reports by the participants of the Bike Buddy Program. There have been instances where a bike mentor took a route that was more direct but included streets that feature complex infrastructure and much traffic. While bike mentors in these cases argued that there was no feasible alternative routes, this route choice was then an issue for the less experienced cyclists, who had been willing to spend more time on the trip if the cycling experience itself would have been more pleasant in return. The more experienced cyclists, however, perceived these situations as something that required skill and know-how, where they needed to apply strategies that were mostly grounded in and developed from their practice. This indicates that these competencies were enabling the experienced cyclists to proficiently cope with these situations, and thus, experience them in a different way than the novice cyclists did.

4.5.4 A Challenge for One

Most study participants on most rides were riding alone. For those that tried to adopt cycling, this meant dealing with all challenges that came along the way – from finding routes to applying traffic laws and good practices for interacting within traffic – alone. So while it is normal to have driver's education or support in starting any other new complex activity, adopting cycling for one's transportation needs is a lonely activity. A possible explanation may be that knowing how to ride a bike is implicitly seen as being able to ride a bike in any "common" context. However, while participants in the previous case studies all were able to ride a bicycle, multiple participants reported negative emotional responses such as being scared or fearful when riding. Hence, one might be familiar with a specific context, e.g., a particular area within a city, as a pedestrian, car driver or using public transport, and be able to ride a bicycle. However, this does not yet mean that one is able to *comfortably* ride a bicycle within that familiar area.

A potential help in overcoming this can come from family members, partners, or colleagues. They may be familiar with cycling in the same areas and can provide support in many different forms. Examples across the previous case studies included them showing cycling routes, answering questions around bicycle storage, providing help for bicycle repair, and offering motivational support through encouragement. At the same time, in Case Study III (Bike Buddy Program) I found that riding together is both difficult to arrange for, and not necessarily perceived particularly helpful to novice cyclists. This contradiction has implications for design discussed in the next section.

4.6 Discussion

The effect of introducing technology interventions on the adoption and use of the bicycle has been the overarching research question behind the three case studies presented in this chapter.

These case studies offer vital insights that inform the subsequent studies: First, a technology designed around social features should have a real social context, i.e. exist within an existing social setting. For example, many things in the Frequent Biking Challenge were seen as having little meaning as the other participants were strangers. Second, implications for design derive from the finding that participants wanted to simply *try out* biking for their daily needs. Technology facilitating bicycle usage has to offer a seamless user experience for initially signing up and using a bike-sharing scheme. By that, it enabled the "trying" of cycling for one's personal transportation needs, which may eventually lead to repeated choices to do so. Third, ICT can play a role in providing in-the-moment support for the challenges faced when adopting cycling. For example, some route segments are more likely to produce negative experiences. Therefore, the implication for design is to use technology to provide in-the-moment support on a given route or to offer routing alternatives, that is, offering systems that facilitate more positive cycling experiences. Fourth, some participants had no bicycle rides during the study period, despite the provision of a bicycle and the study intervention. These case studies provide initial pointers for underlying reasons, particularly negative experiences – or the expectation of those – when using the bicycle. Fifth, while support from more experienced cyclists was appreciated in the abstract, riding together as a learning activity has been difficult to arrange and was not necessarily an opportunity to learn. Information and communication technology could address these problems, which I will investigate in Chapter 6 by narrowing down on cycling for beginners and the role technology can have therein.

These case studies also highlighted the overall dynamics of choosing to use the bicycle. In line with existing literature (e.g., Wardman, Tight, and Page 2007; Heinen, Wee, and Maat 2010), considerations of travel time and cost affect the choice to use the bicycle. The case studies also showed the difficulties of adopting cycling as a practice within one's everyday life. Most prominently – and in line with existing literature – was the lack of bicycle infrastructure. Related to that were difficulties finding a good route that strikes a balance between travel time and travel comfort, a finding that is in line with earlier research by Stinson and Bhat (2005). However, even given short travel times, a comfortable route, and low costs, there is still the issue of access to a bicycle needed to choose using it. Furthermore, with limited support from urban planning, infrastructure policy, or traffic law, unpleasant experiences while cycling remain and create key moments that can make the adoption of cycling unattractive. Technological interventions should consider those challenges of adopting the practice.

A limitation of the three case studies presented in this chapter lies in their initial design focused on assessing the effects of the technology intervention based on quantitative indicators – those included choices for cycling or the pre-post intervention comparison of perceived safety and perceived self-efficacy. Larger study groups would be thus needed to draw more confident conclusions, particularly given the variance within data on the choice to use the bicycle. The qualitative data gathered included open questions in surveys and interviews with participants. A larger number of interviews and expanding the applied qualitative methods, e.g., observations, qualitative diaries, or cultural probes, would likely have enabled additional insights but were not included in the study designs due to limited resources.

4.7 Chapter Summary

This chapter presented the first three case studies on the role ICT can have in supporting utilitarian cycling. Two of them use a technology probe, to explore the space of using information and communication technology for supporting cycling. The first case study was the "Frequent Biking Challenge", which used a game-like approach to motivate participants to start cycling or cycle more often. While quantitative data did show a substantial increase in trips done by bike during the study period, the small size of the intervention group and conflicting qualitative data raises questions about the group dynamics, motivational aspect and long term effects. Those will be addressed in the subsequent chapter. The second case study was concerned with the role of competencies and skills that are necessary for utilitarian cycling, particularly within urban areas. The intervention of the "Virtual Bike Tutorial" was designed to provide training of essential urban cycling skills in the safe setting of tutorial done on a desktop personal computer. We found that the intervention was too unrealistic to produce effective experiential learning. The third case study did not involve a technology probe, but rather explored how beginning cyclists are supported by experienced cyclists in general. While this ride as a pair was generally perceived positive, integrating it into one's everyday routines was difficult to achieve. It was shown that regular cyclists can share their competencies, particularly of strategies learned through experience, with novice cyclists. But while both were riding in the same situation, the novices did differentiate themselves from the more experience cyclists. The implications for technology design are to investigate providing a supportive system which could be easily integrated into everyday rides that is tailored particularly for "interested, but concerned" (Dill and McNeil 2016) people on bicycles. This will be followed up in Chapter 6.

The results across those case studies show that the adoption of cycling – that is integrating it into one's own daily routines – is shaped by many aspects. These include e.g., time and cost considerations, the available cycling infrastructure, and past unpleasant experiences on the bike. This finding is in line with existing research on cycling (e.g. Heinen, Wee, and Maat 2010; Pucher and Buehler 2008; Dill and McNeil 2016). The role of this vast set of aspects has, however, not been explicitly used to structure or inform technology designs. As a first step to do so, I investigate the role of ICT in supporting cycling on different levels of concern. There is the view on cycling as a choice. Access, time, cost, convenience, motivation or habit are some key aspects in that regard. Then, there is cycling as an in-the-moment activity. It involves composing a range of practices, from balancing and steering the bicycle, navigating existing built infrastructures, and interacting with other traffic participants. An individual can experience this e.g., struggling to "do the right thing", feeling intimidated by other traffic participants, enjoying the movement and independence, or being angry at the lack of infrastructure. Beyond the individual, this can be viewed as the practices that together form the social practice of cycling. These emerging distinct views on cycling – motivation and choices on one side and the in-the-moment *doing* of cycling on the other side – are explored in more depth in the two subsequent chapters.

CHAPTER 5

Choosing Utilitarian Cycling: Technology to Motivate

In the previous chapter, I explored the interplay between information and communication technology and cycling. Taking up cycling for everyday, utilitarian purposes, involves many aspects, e.g., the availability of a bicycle, the distance of regular trips, possible routes, and the competencies to handle riding in traffic. Given that, one has to choose to use the bicycle. Within this chapter, the role of ICT for those choices becomes a central point of research. A part of this is how choices are connected to our everyday things, where ICT is becoming an ever more pervasive part. Smartphones, in particular, enable us to do various activities – e.g., communicating with others, use of services, seeking information, etc. – at almost any time and any place. These technologies help us keep track of to-do lists, remind us about dates, keep us informed, and help us achieve goals. The latter often includes learning, being more mindful, or being physically active. In this chapter, I explore such ways of using technology to provide motivational support for adopting cycling for one's transportation needs within everyday routines. I therein ask the second research question of this thesis (RQ2): *How can information and communication technology provide motivational support for the choice to cycle?*

Information and communication technology can be an essential facilitator in initiatives that promote cycling. Previous research indicates that those can affect participants choices to cycle (Rose and Marfurt 2007; Piatkowski et al. 2015; D. Ogilvie 2004). ICT can therein be used for tracking, and introducing game-like elements and feedback mechanisms as shown in Chapter related work 2 or as indicated by Case Study I (Frequent Biking Challenge). However, more details on what motivates users to participate and choose cycling and how technology provides practical support are still lacking. Furthermore, the Frequent Biking Challenge intervention from the previous chapter revealed the importance of an actual social context – as it was missing that. The small group sizes also did not allow us to draw more general conclusions between the intervention and the transportation mode choices. Furthermore, the amount of qualitative data was limited. In this chapter, I investigate the interplay of ICT and transportation mode choices, with an emphasis on utilitarian cycling, at a larger scale and a broader scope. The goal is to describe technology designs, motivations, and social contexts and how these are all entangled with everyday transportation choices.

For this, I present two case studies that explore the role of ICT in providing motivational support to choose cycling. With the emphasis on motivations and choices of individuals, Case Study IV evaluates Bike to Work – an existing program that promotes commuting by bicycle. The insights gathered from this and findings from the previous chapter inform Case Study 5.2, a technology intervention at a larger scale that uses gamification elements to encourage choosing cycling. Subsequently, the findings across those two case studies are discussed, shining a light on designing ICT interventions for choices. The discussion of the results and limitations of these approaches will then lead to the subsequent chapters.

Similar to the previous chapter, the case studies presented herein were also part of the research project between the Media Lab at the Massachusetts Institute of Technology (MIT) and the AIT Austrian Institute of Technology. Alexandra Millonig, Agnis Stibe, Ryan C.C. Chin, Stefan Seer, Katja Schechtner, and Kent Larson have been involved in this project. Geraldine Fitzpatrick provided generous support and guidance for my academic development, writing and thinking. Within this chapter, I use the pronoun "we" to refer to activities where my colleagues contributed substantially to the work presented in this chapter. The findings from Case Study IV have been published and presented at Transportation Research Board (TRB) 95th Annual Meeting 2016.[1] *The findings from Case Study V have been published and presented at DAPI 2016: Distributed, Ambient and Pervasive Interactions.*[2] *The chapter is based on these publications.*

5.1 Case Study IV: Bike to Work (Radelt zur Arbeit)

"Bike to Work" (in German: "Radelt zur Arbeit") was a nationwide program to encourage people to cycle on their commute. The Austrian biking advocacy group Radlobby Österreich conducted it with financial support from the Austrian government. Bike to Work was held each year during May and took place for the fifth time in 2015. In that year over 14,800 participants joined the program, making it the largest of this kind in Austria. At the time of writing (2021), it is no longer conducted as described here and has been replaced with a new program called "Österreich radelt" (in English: "Austria is cycling")[3].

[1] The publication related to this is: *Wunsch, M., Millonig, A., Seer, S., Schechtner, K., Stibe, A., and Chin, R.C.C. 2015. Challenged to Bike: Assessing the Potential Impact of Gamified Cycling Initiatives.*

[2] The publication related to this is: *Wunsch, M., Stibe, A., Millonig, A., Seer, S., Chin, R.C.C., and Schechtner, K. 2016. Gamification and Social Dynamics: Insights from a Corporate Cycling Campaign. In: Streitz N., Markopoulos P. (eds) Distributed, Ambient and Pervasive Interactions. DAPI 2016. Lecture Notes in Computer Science, vol 9749. Springer, Cham.*

[3] `https://nationaler-radverkehrsplan.de/de/aktuell/nachrichten/aus-radelt-zur-arbeit-wird-oesterreich-radelt`

Studying this existing program allowed us to gather further insights into how outside interventions can provide motivational support to choose cycling. Furthermore, it allowed us to understand the connection between an intervention and existing social contexts. Those insights then informed the technology probe in the subsequent case study. The guiding research questions of this case study have been: *(1) What ICT and campaign designs does the campaign Bike to Work use to encourage cycling? (2) What are the effects of participating in Bike to Work on transportation mode choices?*

Program Design

The initial step to join Bike to Work is a sign-up on the program's website. There, one had to form teams of two to four persons who also had to sign up. One could also volunteer to become a company coordinator, who helped their colleagues to register and create or join teams. Those company coordinators should also promote the program within their company. Bike to Work provided incentives to its participants in the form of different prizes, e.g., vouchers for leisure activities or bike gear. These were distributed by two means: First, all teams where each member commuted on more than half of all workdays entered a lottery to win prizes. Second, participants were randomly selected and called by phone asking if they commuted by bicycle that day. If they did, they received a prize as well.

People enrolled on the program could either track their daily commutes with a smartphone app or log in to a website to insert the distances covered by bike. The team performance and the individual mileages were shown within the app and on the website. Figure 5.1 shows the tracking tab and the statistics tab of the Bike to Work smartphone app.

In my analysis, the design of Bike to Work included these features to affect participants' motivation and choices:

- **Commitment:** By participating in the program, a commitment to commuting by bike is visibly made. Other team members know of this commitment and may provide support, reminders or other critical feedback.
- **Competition:** The comparison between one's individual performance to other team members, and between the team's performance to other teams can create motivation grounded in competing with others.
- **Tangible incentives:** As described above, people who joined Bike to Work had the chance win in a lottery or receive a prize. These incentives can provide additional extrinsic motivation.
- **Reflection and raised awareness:** By regularly reporting mobility choices, participants reflect on their transportation habits. This is similar to the findings shown in the previous chapter.

Figure 5.1: Screenshots of the Radelt zur Arbeit (German for Bike to Work) app showing the tracking tab (left) and the statistics tab (right)

5.1.1 Methods

Study Sample

I conducted this study in the year 2015, when 14,809 people participated in Bike to Work. Out of those, 498 individuals enrolled in the study. They primarily had to answer a standardised online questionnaire. Out of all survey respondents, 157 provided additional qualitative data by responding to open questions in the questionnaire. A question regarding mode shifts was added to the questionnaire later while running the survey resulting in n=92 for this item. Additionally, nine participants participated in one-on-one semi-structured qualitative in-depth telephone interviews.

Study participants were recruited with a link on the campaign's website and different social media channels. They were eligible to participate in a lottery offering the winners bike racks for their workplace. This opportunity may have caused a selection bias, as regular bikers might be more interested in having sufficient biking infrastructure and generally more interested in the initiative.

Collection and Analysis of Data

The standardised online questionnaire included questions about the respondents' overall perception of Bike to Work, cycling choices before and during the initiative, potential long-term changes, and the influence of different motivational factors encouraging biking. Participants could provide additional open comments. The content of the in-depth telephone interviews was audio-recorded and partly transcribed for the analysis process. The qualitative data was analysed using thematic analysis as described in Chapter 3.

The comparison of the distribution of motivational factors between groups of participants was done using Pearson's chi-squared tests with Yates' continuity correction. Estimates of proportions within all participants are based on sample means. 95% binomial confidence intervals are based on Clopper and E. S. Pearson (1934) and fulfill the requirements according to Brown, Cai, and DasGupta (2001). The statistical analyses were conducted using R (R Core Team 2015).

5.1.2 Results

Participants of Bike to Work had an overall very positive attitude towards the program. The question: "How do you like 'Bike to Work 2015'?" could be answered on a scale ranging from "1 – Not at all" to "7 – Very good". The initiative achieved an average rating of 6.3 [SD=1.00]. The in-depth interviews have also reflected this result, where all respondents expressed their satisfaction with Bike to Work.

Motivational Aspects

People enrolled on the program report distinctly different likelihoods of commuting by bicycle. 55% reported that they usually commute by bike almost daily ("daily bikers"), 24% bike several times a week ("regular bikers"), and the remaining 22% ("occasional bikers") bike less often than that. The descriptions provided by participants reflected this mix of participants, resulting in a dynamic where regular bikers motivate occasional bikers. Table 5.1 shows the distribution occasional, regular and daily bikers within the study.

Motivations to commute by bicycle while participating in Bike to Work differed depending on the usual frequency of bike commuting as shown in Figure 5.2.[4] The strongest motivator on average was environmental protection, which is of equal importance across all three groups. Health benefits were most important for occasional cyclists showing that bike commuting is seen as a way to live a healthier life and include physical activity into everyday routines. Statements within the interviews have also confirmed this: "Otherwise I would often be too lazy to do some sports in the evening after I got home from work. But by commuting by bike one has to use the bike to get home as well and one has to

[4]The numeric values are reported in the appendix to Chapter 5

Table 5.1: Overview of group sizes for regularity of biking and change in frequency of bike commuting during the campaign

Group	**Occasional bikers**	**Regular bikers**	**Daily bikers**	**Full Sample**
Commute by bike	never to (almost) weekly	several times a week	(almost) daily	
Respondents *)	107	117	272	496
Change during Bike to Work				
Biked more often	78%	52%	13%	36%
Biked the same	22%	48%	87%	64%
Biked less often	1%	0%	0%	0%
Total	100%	100%	100%	100%

*) Two respondents skipped this part of the survey.

pedal" (p224). Here bike commuting and the decision to bike is even a way of committing oneself to be physically active. Commuting by bike may take more time than available transport alternatives, but it doubles as a physical workout. A gain in health and fitness thus compensates for the lost time. If doing sports is substituted with bike commuting on long distances altogether, this can even be time-efficient: "Although I need over an hour one way, overall I am saving time" (p082). By that, Bike to Work provides a support structure to start or increase bike commuting as a way of doing something for one's health. Health benefits were a significantly higher motivator for occasional bikers (70%) and regular bikers (60%), compared to 46% of daily bikers [χ^2=16.2, n=369, p<0.001 and χ^2=5.5, n=382, p=0.019].

Team spirit, i.e. doing something together as a team, was related to three social processes: First, collaboration, as participation required each team member to stick to the 50% bike trips rule to qualify for the lottery. Second, increased visibility of mode choices, as daily transportation choices become subject to judgements by others. "On days I commute by car I'll get some 'friendly' remarks from colleagues" (p224). Third, competition, as for some participants being in a team also meant competing with others. "We have two teams, and this year there was quite some competition going on" (p310 "Teams within our company that biked about the same as we did sent an email stating: 'Look, we have overtaken you in the ranking'" (p224). Being motivated by team spirit was mentioned significantly more often by occasional bikers at 58% compared to regular bikers (46%) or daily bikers (41%) [χ^2=2.96, n=219, p=0.08 and χ^2=8.24, n=369, p=0.004], showing the importance of participating together with colleagues and friends and that this is more relevant and more motivating for occasional bikers.

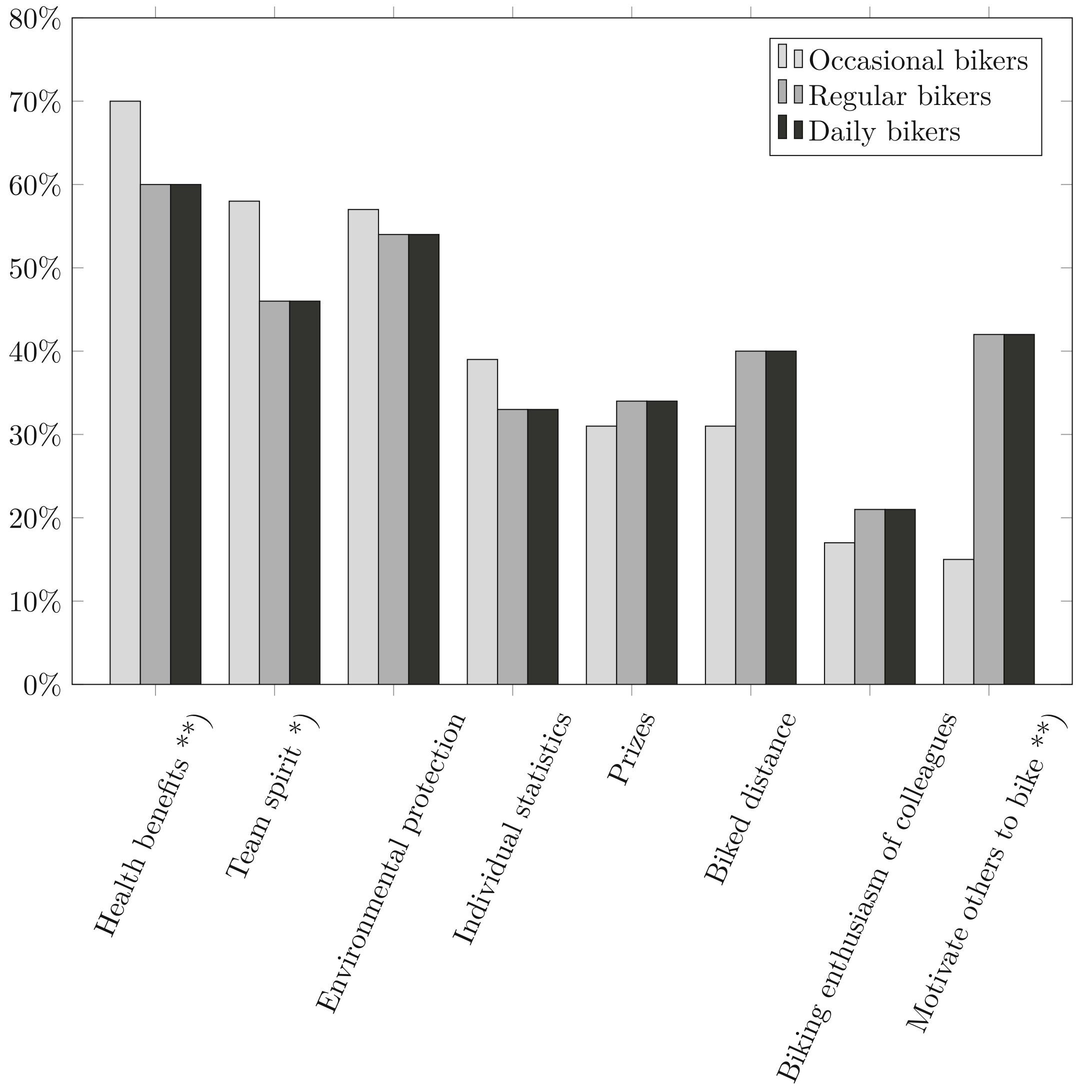


Figure 5.2: Motivations for participating in Bike to Work.
Question: “What motivated you while you were participating in Bike to Work?” *) significant difference between groups: Chi-Squared, p-values <0.05
**) significant difference between groups: Chi-Squared, p-values <0.01

Motivating others to chose the bicycle was a motivator primarily for regular and daily bikers to join Bike to Work (p<0.001). “I daily bike to work anyway, but with this initiative, more people get motivated, and some may stick with it” (p89). Several respondents reported on the effectiveness in this respect, expressed in statements such as: “Because of Bike to Work I could motivate two colleagues to bike commute” (p10). “Since we had started two years ago, I could persuade my brother in law as well as colleagues of mine to bike commute, especially as I am riding even during winter" (p106). This result also demonstrates the interrelation of motivational factors for daily and regular bikers compared to occasional bikers, as Bike to Work provides the former with an opportunity to promote biking and get non-bikers and occasional bikers excited about the idea of bike commuting. This effect can be seen in Figure 5.2 in the higher values of "motivate others to bike" for the regular and daily bikers and the higher value of "team spirit" for the occasional bikers. This result has been present in the data gathered through interviews and open questions as well: "This initiative is ideal for raising my colleagues' awareness for biking" (p437). The formation of teams consisting of occasional and regular bikers may also set a norm for the regularity of bike commuting: "Some in my team are already biking a lot; others were not so much before the initiative" (p310). This role of already frequently biking people is comparable to previous findings by Piatkowski et al. (2015) pointing out their role for awareness-raising and motivating others.

Although prizes and the possibility to win them in the lottery are a central feature of this program, they rank only fifth within the list of motivators, being relevant for 36% of participants. This could indicate that social interactions and mutual engagement introduced by the program being at least equally relevant. However, prizes could motivate people to join Bike to Work in the first place. For them, as for the remaining motivations – personal statistics, biked distance, enthusiasm of colleagues – no significant differences between the three groups of participants emerged.

Another relevant aspect is the role of the employers, i.e. companies or organisations. They can support choices by their employees to commute by bicycle, to engage in healthy activities, and contribute to increased ecological sustainability. In these situations, Bike to Work provided a helpful framework. One company created a corporate social responsibility project that was inspired by Bike to Work. Another company was actively encouraging employees to join Bike to Work by providing information material, helping with the teams' set-up process, and even organising a kick-off event. Besides that, many private and public organisations help distribute information about Bike to Work to their employees.

Changes in Bike Commuting Frequency

Table 5.1 shows the change in bike commuting frequency during the program. Within the full sample, 36% increased their frequency of bike commuting during Bike to Work. Among the occasional bikers, more than three out of four (78%) biked more often than usual during the month of the initiative. This group, which can be regarded as the ones drawn into more regular biking by the campaign, account for 17% of all Bike to Work participants [95% CI 14%, 20%]. One reason for this change was that the campaign acted as a trigger to try bike commuting. One participant (p99), who moved to a new town six weeks before joining Bike to Work, used to drive on her commute of 1.7 km (1.1 mi). Getting information about the program from her employer, knowing about other teams that participated in the previous year and having a colleague who already biked daily to team up with, made her start to ride the bike for her commute. Another participant rediscovered biking due to the campaign: “I used to live in a small town and biked a lot back then, but as I moved to a bigger city and had small kids, I almost never used the bike. Now I have rediscovered biking” (p351). Another driver for the high share of increased bike use during the initiative within the occasional bikers can be found in the eligibility criteria for the lottery (minimum of 50% bike commutes per team member), which required a significant change of the participants’ mobility choices. This led to a temporary change to achieve the goal: “It is okay for one month. But for me it is also very cumbersome” (p367).

Although the general frequency of bike commuting in the group of regular bikers is already high, 52% increased their bike use during the program. The analysis suggests that this stems mainly from changes in situations where participants usually would not have chosen to ride the bike to work, i.e. on days with bad weather. Typical statements for this group include: “[Bike to Work] is indeed motivating us all to ride the bike, even when the weather is bad” (p106), “I ride now even when it is raining whereas previously I would have taken public transport” (p246), “Before [Bike to work] I took the car when there was rainy weather. Now I am riding my bike and even if there are some scattered showers I will be fine” (p224).

Among the daily bikers, a comparatively low number of 13% increased their bike use, which is expected given that this group is already mainly using a bike to get to work. The increase can be mainly attributed to the same changes of riding even though the weather is less favorable. Regarding transportation mode shifts, 39% of the participants [95% CI 28%, 49%] reported a reduction of trips by car and 34% [95% CI 25%, 45%] a reduction in their use of public transportation.

Long-Term Effects

Survey respondents who also participated in the Bike to Work initiative in previous years (n=381) were asked to assess the resulting long-term effect. Based on the responses, it is estimated that 26% [95% CI 24%, 29%] of Bike to Work participants increase their level of bike commuting in the long run, which is in line with findings of Rose and Marfurt (2007). “I will extend ‘Bike to Work’ and will continue to bike to my workplace. I realised through this initiative how great it is to bike to my work. I am very enthusiastic and enjoy it every day” (p099). In retrospect, one respondent stated: “Bike to Work 2014 has been the trigger to switch completely to the bike within the city and closer distances. Meanwhile, I am using the car just for trips over 100 km [62.1mi] or for hauling. I sold my own car, and I almost never need public transport” (p229). Although such drastic changes might be the exception rather than the rule, the data indicates a long-lasting effect. Additionally, 5% of the respondents stated that they had increased their bike commuting for a short time after Bike to Work but subsequently returned to their usual mobility choices.

5.1.3 Discussion

The first question for this case study asked what technology and campaign designs are used by Bike to Work. By relying on existing social structures that are existing at workplaces, potential users are reached using existing communication and collaboration structures. These organisations can also facilitate engagement within the company, typically by management supporting the program to become more environmentally friendly and healthy. The design of Bike to Work also puts teams at its centre. As shown in Figure 5.1, a user's team is featured prominently next to the own personal data. The results showed that dynamics within those teams emerge, from collaboration to reach goals together to increased visibility and commitment to compete with other teams.

What could also be shown is the drive towards motivating others to cycle (more). As most regular cyclists know the benefits of cycling from their personal experience, they want to help others do the same. Another driver is the interest in urban planning, that is, the idea that more people cycling will generate more political pressure to provide good infrastructure.

Tangible benefits are also used in Bike to Work. However, the results suggest that they are less critical as motivators to cycle more. This finding implies that a system could offer e.g., a platform to collaborate and participate without offering any tangible benefits to its users. Raman Kazhamiakin et al. (2021) recently developed and evaluated such a gamification platform. Their design achieved long-term engagement over 6-months and found that 45% of users did try more environmentally sustainable transportation options.

The second question asked about the effects of participating in Bike to Work on transportation mode choices. The results showed an overall increase in bicycle usage. Previous studies asking this question examined only one-day bike-to-work events. Similar to the findings in this case study, Piatkowski et al. (2015) identified different groups that participate in bike-to-work events. In their evaluation of a ride-to-work day in Australia, Rose and Marfurt (2007) found that 27% of participants who rode to work for the first time on that day still did so five months later, which is in line with the 26% reporting a long term increase in cycling within this case study. For children this might be notably different, as Crawford (2011) and Reutter (2004) did not find a lasting effect on campaigns to promote active transportation to school.

The insights derived from Bike to Work and other similar programs to promote cycling can inform designs of systems that support its users to adopt active transportation in their everyday routines. The design in the subsequent case study represents an instance of such a system.

5.2 Case Study V: Biking Tourney

We developed another technology probe to gain further insights into how technology can provide motivational support for choosing to use the bicycle. It was a web-based platform, called the Biking Tourney, which introduced a competition between organisations on commuting to work using the bicycle.

Informed by the previous case study, the Biking Tourney used a design that introduced game-like elements to daily transportation choices. It also was based on an existing social context, in that companies serve as communities that provide communication structures, shared spaces and time, and a shared identity for their employees. The design intention thereby is to facilitate social interactions and mutual encouragement for cycling as was found in the Case Study on Bike to Work. In contrast to that, no tangible incentives were provided to the companies or participants.

In this section, I present the outcomes of providing organisations with the Biking Tourney for six weeks. Thereby, the following research questions are addressed:

- *Can a system designed around playful competition between organisations engage employees in commuting by bike?*
- *What group dynamics are introduced by such a system?*
- *What role for individual's motivation do different design elements of the system have?*

The following section outlines the design of the Biking Tourney, followed by a description of the methods to evaluate it over the six-week study period. The main section provides the detailed evaluation results for the study. The concluding discussion situates the findings within the existing research literature and the results from the previous case studies. It concludes with implications for similar interventions in the future.

5.2.1 Design

The design of the Biking Tourney included four different categories related to bike usage. The participating companies were ranked in each category. The goal for participating companies was to rank as high as possible within the categories of the Biking Tourney. Three of the rankings were introduced at the beginning: (1) "Bikers" reflected the share of biking employees and should encourage participation as well as motivating others to join the tourney. (2) "Average distance" reflected the effort a company's employees invested in the Biking Tourney while not being influenced by the actual employee count of a participating company. (3) "Total distance" honoured the total mileage of the biking employees. It favoured larger companies. After the initial three weeks, the fourth ranking called "enthusiasm" was introduced, which showed a score of the change in the share of bikers over time. Thereby companies with low drop-outs and employees joining even after the official start were higher ranked. Figure 5.3 shows the graphical representations of these categories which were provided to the participants during the tourney.

The different ranking schemes were designed to compensate for potentially demotivating settings for participants, for instance, being in the lower ranks or having a disadvantage

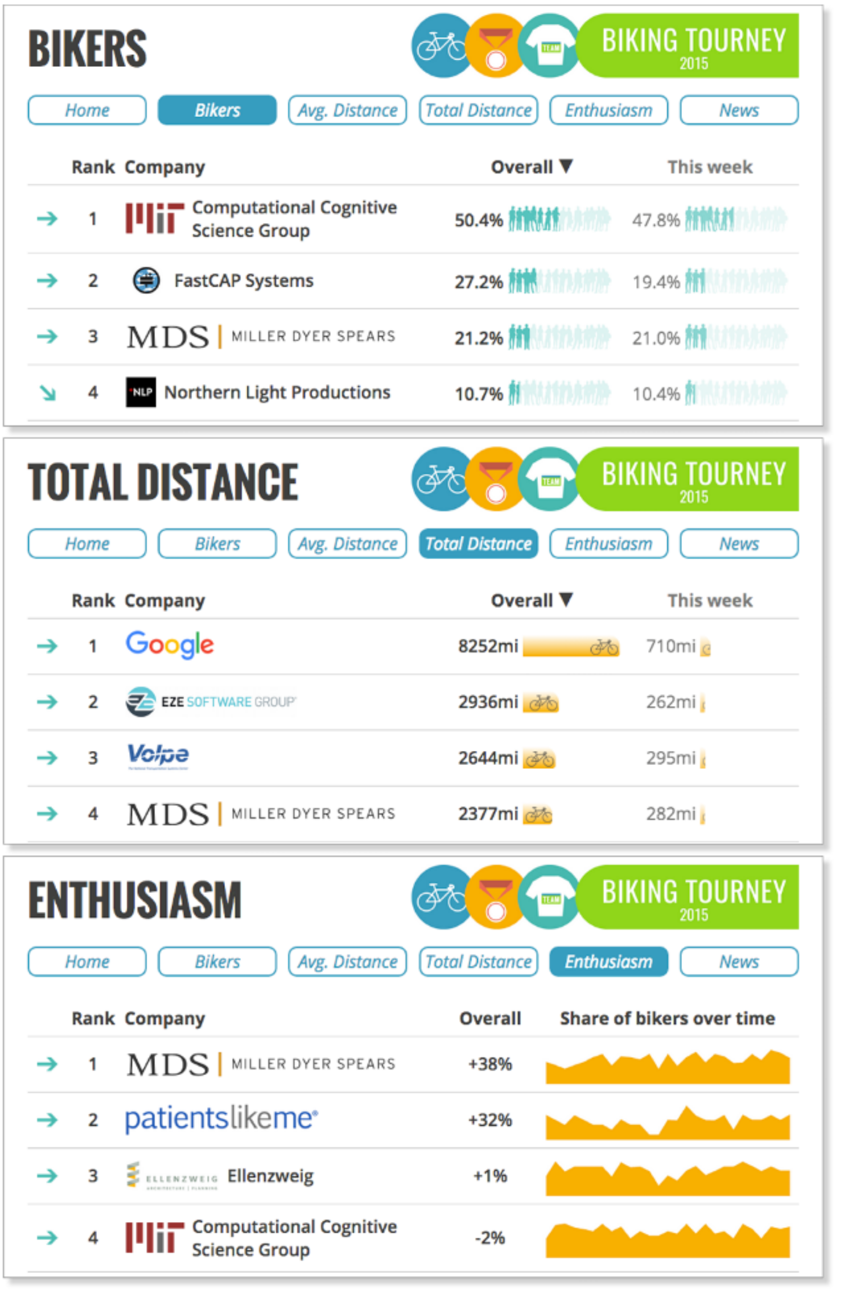


Figure 5.3: Biking Tourney visualizations: rankings for bikers (top), total distance (middle) and enthusiasm (bottom)

Figure 5.4: Public displays with the tourney rankings in the participating companies

because of the company size. Hence, the assumption was that when providing several rankings, a low standing in one of them is not as demotivating as in a single category design. The hypothesis is that competition among organisations would provoke cooperation among employees in each organisation. Furthermore, the use of publicly displayed rankings in common areas of the companies – as shown in Figure 5.4 – should raise awareness of the Biking Tourney and facilitate commuting by bike (Guerin 2010).

Mobility data in this initial version of the Biking Tourney was gathered using a web application for self-reporting similar to Case Study I. Hence, cheating could not be easily prevented. We conducted manual sense checks of the reported data during the study period. Implausible data, e.g., due to errors in the web application, could thus be identified. We had one such instance, where we then reached out to the affected participant to ask about his actual cycling trips. This information was then used to correct the reported trips.

5.2.2 Methods

Intervention Context

After contacting 227 companies, a total of 14 companies took part in the Biking Tourney. Those companies varied largely in size, with employee counts ranging from 17 up to about 10,000. All companies or their respective local offices were located in the Greater Boston Area (MA, USA). The companies did not receive any incentives for taking part in the study. The evaluation of the Biking Tourney platform took place in September and October 2015 and lasted for six weeks. The participants generally described the weather during the intervention period as good biking weather except for one week with several rainy days.

Study Sample

Within the study, 239 people registered for the Biking Tourney. The mean age of participants was 39 years (SD: 11 years), the gender distribution was 18.6% (44) female, 81.0% (192) male and 0.4% (1) gender-neutral. Two aspects help explain the over-representation of male participants: First, the company with the highest number of participants had a large share of men among its workforce (about 70%). Second, the overall share of cyclists within the US is tilted towards men, similar to many other countries (Heinen, Wee, and Maat 2010).

The mean commuting distance - home to work - was 7.7km (4.8 miles) with a standard deviation of 6.1km (3.8 miles). Based on a survey the participants took during the sign-up, 60% were usually commuting by bicycle almost daily, 24% were usually commuting by bike up to several times a week, and 16% were using their bike less often than that. All of the participants had been commuting by bike before the tourney.

Out of all study participants, 127 filled out the ex-post survey. For them, the mean age was 39 years, with 17% (22) female and 83% (104) male participants.

Collection and Analysis of Data

Quantitative data was gathered by pre- and post-intervention online surveys. All participants had to fill out the pre-intervention survey during the sign-up for the Biking Tourney. Participation in the post-intervention survey was voluntary. The surveys contained standardised questionnaire items for descriptive statistics and cross-tabulation. The post-intervention survey also contained a set of open questions regarding the overall effect of the tourney on one's commuting routines. Furthermore, nine qualitative interviews with the company representatives, i.e. our contact persons for each company, were conducted during the Biking Tourney. We collected the data from these interviews as written notes.

The quantitative survey data was analysed using cross-tabulation to highlight the effects of the intervention for different types of participants similarly to the previous case study. Qualitative data from the interviews and the open-questions in the questionnaires was analysed using thematic analysis as described in Chapter 3.

5.2.3 Results

Participants of the Biking Tourney have been positive about the intervention design. The question: "Overall, how did you like the Biking Tourney?" on a scale ranging from 1 "Not at all" to 50 "Very good" the mean rating was 36 [SD=9.8]. Regarding changes in transportation mode choices, 19% planned to commute by bike more often or continue to do so and 79% planned to continue to do their commute as they did before joining the Biking Tourney (based on post-intervention survey). 11% of the respondents reduced the use of their cars, and 17% reduced their use of public transportation.

Motivational Aspects

The ex-post survey asked for different motivational aspects for joining the Bike Tourney. The results are shown in Figure 5.5. Cooperation among employees of each organisation was a driving factor for participation, with 46% of participants crediting "team spirit / participating together as a team" and 42% saying that their colleagues were motivating. A total of 30% agreed with "joining as a way to motivate others to bike", highlighting the role of cooperation among participants. "I bike most every day anyway. I do appreciate the encouragement for others" (p205). Personal health benefits were a relevant motivator for 41% of participants; the available statistics did motivate 35% of participants, and competition with other companies has been a motivator for 35%. Although often mentioned concerning biking, environmental benefits were the lowest-ranked motivator with a share of only 28%. Of course, for most participants, a mix of motivators was present: "The tourney gave me more incentive to bike during the week as the exercise is good, faster than transit, and more reliable" (p48).

We found the same theme of colleagues as motivators as in the previous case study. However, the level of engagement and activities of the company representatives varied to a large degree. All of them sent out informational emails to their colleagues, but some were more eager and actively engaged their colleagues to participate regardless of their otherwise used mode of transportation. Internal mailing lists were used to distribute information about the Biking Tourney. Another approach was to hand out flyers or set up social media groups. Like Bike to Work, the Biking Tourney as a platform provided the foundation for colleagues to motivate each other to regularly commute by bike or try out doing so.

Another motivator for participating was advocacy for improved bike policies. The company representatives and individual Biking Tourney participants stated that they want to signal to the city that there is demand for better infrastructure for utilitarian biking. As a participant stated, he was "hoping that the statistics will improve safety for cycling and bring attention to improved urban planning for commuting on bike in Greater Boston" (p76).

Change in Frequency of Bike Commuting

Participants in the Biking Tourney reported their preexisting frequency of bike commuting at the sign-up process. Based on this, three groups of participants similar to the Bike to Work evaluation were identified: (1) Occasional bikers, commuting by bike monthly to weekly, (2) regular bike commuters are those commuting several times per week by bike and (3) daily bike commuters. Notably, the latter two groups represent 84% of the

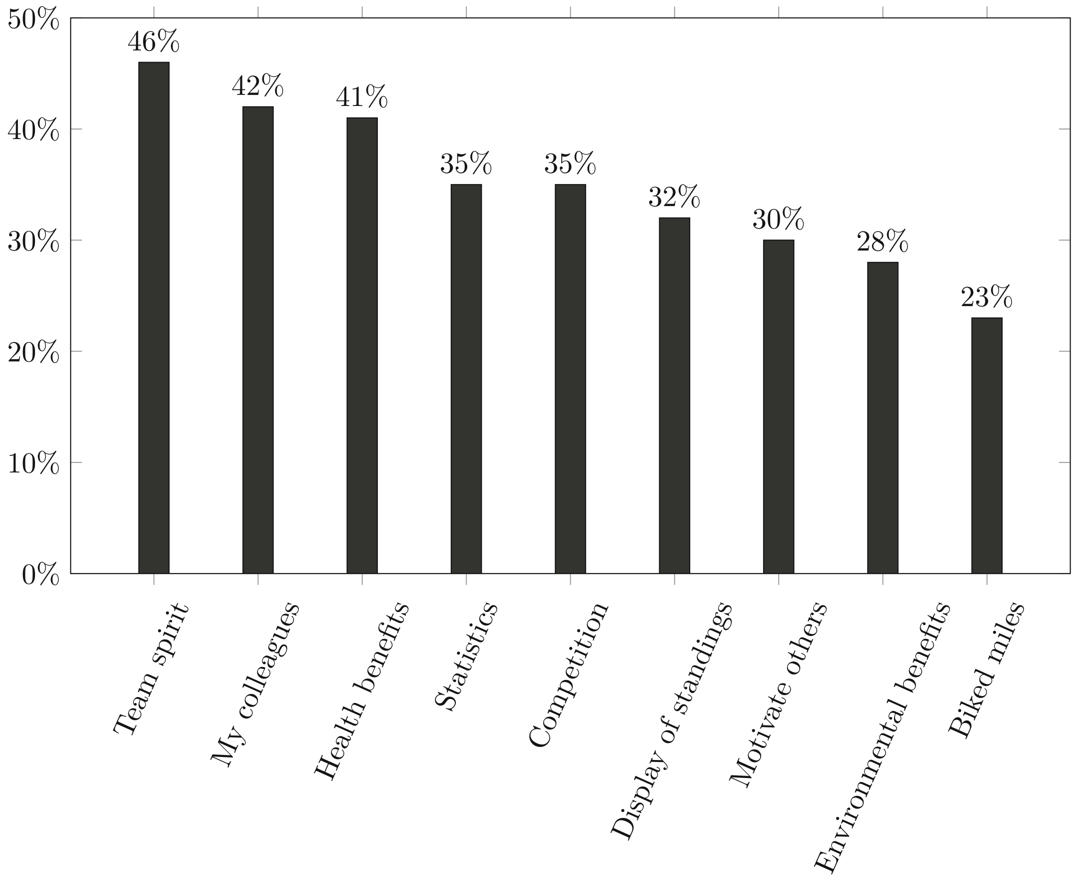


Figure 5.5: Motivations for participating in the Biking Tourney. Participants could select the items that they agreed with (dichotomous scale). n=127

tourney participants and are slightly over-represented in the ex-post survey with a share of 90%. Furthermore, all Biking Tourney participants stated that they commuted by bike before, implying that the tourney did not encourage non-biking employees to try to commute by bike.

Table 5.2 shows the changes in the frequency of commuting by bicycle during the 6-week evaluation. Similar to the previous case study, these changes are based on survey data. A total of 79% of participants remained at their level of bike commuting, indicating no change due to the tourney. “I always bike to work, so it was the same as usual” (p50).

Overall 15% reported an increase in commuting by bicycle. A comparison by group shows that the increases in bike use were most present for the occasional (31%) and regular bikers (25%). For them, the tourney acted as a means for making bike commuting more of a habit. “Last spring the Mass Bike Challenge helped me realise that I could bike the 12 miles each way. The MIT Media challenge helped make it more of a routine” (p86). “Due to the tournament, I did seek out a safe route to cycle into work and will use it

Table 5.2: Change in frequency of bike commuting

	Occasional cyclists survey (total) 10% (16%)	**Regular cyclists** survey (total) 22% (24%)	**Daily cyclists** survey (total) 68% (60%)	**Full Sample** 100% (100%)
Usual frequency of bike commuting	monthly to weekly	several times a week	(almost) daily	
Change during Biking Tourney				
Biked more often	31%	25%	9%	15%
Biked the same	62%	57%	88%	79%
Biked less often	0%	14%	2%	5%
other	8%	4%	0%	2%
Total	100%	100%	100%	100%
Survey respondents	13	28	86	127

Survey question: "During the Biking Tourney. . . " (a) "I commuted by bike more often than usually." (b) "I commuted by bike as often as before." (c) "I commuted by bike less often than before." (d) "Other"

more often as a result" (p76). Furthermore, the tourney acted also as a commitment system for in-creasing one's bike commuting frequency: "I have always wanted to bike in pretty much every day. Biking Tourney got me moving towards that goal" (p176). Another effect of the commitment to the Biking Tourney was that participants biked even on days with bad weather, a similar finding to Bike to Work. "Some of my office mates made a bigger effort to bike. [...] It was exciting to see so many of our fair-weather bike commuters take the plunge into cold and wet riding on the days that rained" (p50).

5% reported a decrease in bike commuting, with qualitative data suggesting unrelated, temporary external reasons such as business travel to other places, illness or technical problems with one's bike.

Furthermore, the collected qualitative data supports the interpretation that the Biking Tourney acted as a trigger for choosing the bicycle for commuting more often. It also encouraged some of the occasional bikers trying out to commute by bike: "I took [the] bus before but was pleasantly surprised how much faster taking [the] bike was" (p276). But while this leads to a new commuting habit for some, others came by bike to "[...] try it out and support the regular bike commuters in my office" (p286), but stopped doing so after the Biking Tourney ended. Regular bike commuters commented about the motivating effects on their colleagues as well: "The Biking Tourney is a great boost for folks who were considering bike commuting and who needed a little push" (p93).

5.2.4 Discussion

In this case study, I asked if a system designed around playful competition between organisations could engage employees in commuting by bike. The results suggest that this has been the case, with a share of employees who joined the Biking Tourney choosing the bicycle more often for their commutes. As for the group dynamics, we observed an effect similar to Bike to Work: Regular cyclists use the Biking Tourney to motivate their colleagues to commute by bike.

The results also show that all participants in the study evaluating the Biking Tourney did cycle before. Hence, no one new to cycling joined the Biking Tourney. A reason for this might be the design around it being a competition, which might be more attractive to existing bikers. A self-selection bias was likely introduced through the selection of participants and the voluntary nature of the post-study questionnaire. The results on transportation mode choices are therefore also likely skewed towards a more optimistic view on bike-commuting. In any way, the findings are limited to motivating people to cycle more often but not helping them to adopt cycling in the first place.

5.3 Discussion: Technology and Everyday Choices

The case studies above show how ICT can offer motivational support for the choice to cycle. Their designs are thereby mere instances as there are many other approaches in the design. The focus on game-like elements such as teams, points, and leader-boards, represents one particular avenue of designing for choices. There remain plenty of other approaches that could not be explored thus far. For example, wearable fitness tracking devices that encourage their wearers to reach a minimum level of daily physical activity (Nuss et al. 2021), or how apps for navigation can promote certain modes of transportation (Wagner, Winkler, and Human 2021). The same is true for the design process, which in the future could be extended to include, e.g., participatory design to create such artefacts.

While the first case study in this thesis – Frequent Biking Challenge – started to investigate systems with game-like elements and their interplay with the choice to cycle, the lack of a social setting was found to make its features less meaningful. Bike to Work and the Biking Tourney address this critique by being tied to one's workplace, i.e. an existing social setting. Their artefacts – the app, website, or in the case of the Biking Tourney, the public displays – connect colleagues around the topic of commuting. Thereby they also address the fact that daily commutes – and with it the adoption of mobility practices – mostly happen alone as discussed in the previous chapter. As these artefacts connect people, they bring together long-standing frequent and occasional cyclists. As the artefacts embed the idea of bike commuting into the everyday social context, they facilitate collaboration between colleagues and act as commitment devices, e.g., make one's rides visible to oneself and colleagues.

Such systems that facilitate mutual encouragement and use game-like elements to promote cycling affect the motivation and choices of many participants. During the programs, participants cycled more often for their daily commutes. This effect has been more substantial in Bike to Work, which could be due to more vital social dynamics due to small teams of two to four colleagues or the tangible incentives offered with prizes and lottery. Further research is needed to assess the effect of such programs.

5.3.1 Automated versus Reflective Choices

The motivations for participating in the programs included aspects such as the health benefits of cycling or environmental concerns. As I gathered the data using surveys, it represents participants' reflection on what motivated them, i.e. explaining actions in retrospect in a way that is consistent with personal values and goals. It remains a question if those were the rational reasons for action or the rationalisation to make actions reasonable (Ariely 2010). But beyond those motivations, the results also showed the role of social dynamics that are introduced by having such systems. For example, colleagues started to motivate each other, participants offered support, or commitments were made in a social space. These subtle aspects – being part of a larger team and being committed to using the bicycle regularly – may affect choices to use the bicycle less reflectively by acting on social cues and social rules.

5.3.2 The Role of Game-like Elements

The systems studied in this chapter all included game-like elements. Similar social features are used in most popular sport apps, such as Runkeeper, Map my Run, Strava, Garmin Connect, or Adidas Runtastic.[5] They typically include (a) social activity feeds, i.e. a feed of activities of your friends, (b) challenges, i.e. reaching a specific amount of something within a given time, or (c) segments, i.e. running a specific route segment. The intent behind such features is to help users of the app stay engaged and motivated. However, there is little published research on both using those features and their effectiveness. A recent qualitative study based on user reviews suggests that these social features increase users' continued use of an app (Al-Abbadey et al. 2021).

5.3.3 Changes of Transportation Mode Choices

As for the overall effectiveness in providing motivational support to cycle in the long term, these studies provide initial pointers. Based on the retrospective data from Bike to Work, a quarter (26%) of participants stayed more active by continuing to choose commuting by bicycle. Longitudinal studies would be a way to add credibility to this result.

As integrating cycling as an everyday activity ultimately involves repeated choices,

[5] https://runkeeper.com/
https://www.mapmyrun.com
https://www.strava.com
https://connect.garmin.com
https://www.runtastic.com/

studying the interplay of technology to shape habits could be done by future research. The findings thus far already point to programs that last several weeks instead of days that seem more effective in motivating participants to cycle more often (D. Ogilvie 2004; Rose and Marfurt 2007; Piatkowski et al. 2015).

As for the relation between attitudes and choices, we did not find a close link across these case studies. Theoretical views that assume such a connection, i.e. they explain choices based on attitudes, are typically implicitly viewing humans as rational actors (Sniehotta, Presseau, and Araújo-Soares 2014) and forgo to deliver a more nuanced view for understanding choices. In particular, we did not find that "sensing and reporting information" (Brynjarsdottir et al. 2012), e.g., the saved CO_2 emissions, is in itself a major motivator. Particularly environmental benefits may be an aspect of little relevance for the choice to use the bicycle. The high agreement with them being a motivator in Bike to Work likely represents a generally high environmental consciousness, i.e. an overall awareness of the importance of environmental sustainability. However, as many forces shape our everyday practices, awareness is likely not coupled to changes in action. On the contrary, psychological research has repeatedly shown that cognitive dissonance resulting from behaviour-attitude-gaps is reduced by rationalizing the behaviour or adjusting one's attitudes (Festinger 1962; E. Harmon-Jones and C. Harmon-Jones 2007).

5.3.4 Participation Bias

The participants within the case studies in this chapter did not represent the general population. One has to clear several hurdles to participate in Bike to Work or the Biking Tourney. As for the involved ICT, participants needed a smartphone, to sign up, log in and record their trips to participate. As for cycling itself, they needed the skills for riding a bicycle, be competent to do so on a route for their commute, and have access to a bike. People interested in cycling who do not meet these requirements are therefore left out by such systems designed for staying motivated to use the bicycle more often. Therefore, the case studies in the subsequent chapter that focus on the competencies involved in utilitarian cycling.

5.4 Chapter Summary

This chapter showed how information and communication technology could be designed and affect the choice to use the bicycle. Furthermore, existing social structures like workplaces help create encouragement for stimulating motivation. The designs emphasised game-like elements, which is one instance out of many possible approaches to design for motivation and choice.

With the focus on choices, however, the in-the-moment experiences of cyclists, i.e. their interactions in traffic, with a given street design, other road participants, etc., and their actions thereby are not of concern. Furthermore, such systems offer little support to people without the skills or access to a bicycle that is needed to integrate the practice of cycling into one's everyday routine. The next chapter thus shifts the focus on technology for to provide support while cycling.

CHAPTER 6

Using Utilitarian Cycling: Technology for In-The-Moment Support

The previous chapter emphasised the choice to use a bicycle, that is the act to participate in the practice of utilitarian cycling in the first place. The information and communication technology in the presented studies was designed grounded in concepts around motivation and gamification, as well as social influences. What has been left out so far has been the design and evaluation of technology for the experience of riding a bicycle. The association between the experiential quality of cycling and our choices has been shown in previous studies, e.g., with particularly inexperienced cyclists taking slower routes to avoid stressful situations (Case Study III; Crist et al. 2018; Stinson and Bhat 2005) or memories of cycling influencing mode choices and long term habit formation (Pooley et al. 2013; Telfer et al. 2006). Hence, the work presented in this chapter is concerned with ICT that is situated within the complex interplay of a riding cyclist: Controlling the bicycle, understanding, reacting and interacting with other participants in traffic, using the built infrastructure, navigating and more. Cutting across all those aspects is the need for competencies to successfully cope with such situations. From the skill to keep balance, to knowledge about traffic rules, all the way to more fine grained practices on how to act and interact within traffic. These competencies are combined with material things and meanings in the social practice of utilitarian cycling. This already informed Case Study II, where I explored the use of a virtual tutorial to train those competences. However, as shown, this approach did offer little as it had been too disconnected from the actual cycling experience.

In this chapter I present the design of ICT to support the development of the cycling competencies mentioned above, by asking the third research question of this thesis (RQ3): *How can information and communication technology facilitate in-the-moment support* *for cyclists?* To answer this, I both unpack the competencies involved in the practice of utilitarian cycling, and explore ways to use ICT as a means to train those competencies. This extends the insights generated in the previous chapters with a more contextual, in-the-moment understanding of technology for supporting the choice of cycling within everyday settings. Furthermore, whereas the results in the previous chapter showed effects in starting, increasing and sustaining utilitarian cycling, in this chapter I put an emphasis on the experiences and challenges people face while initially adopting cycling that have been already described in Chapter 4.

I therefore present two more case studies: In the first one (CS VI) I investigate how novice cyclists are supported by professional cycling instructors. There, the coaching strategies used in these settings and the experiences of the cyclists are uncovered. I also highlight limitations of these programs and the opportunities for a technical system to provide situated support. In the second case study (CS VII), I describe the design and evaluation of the subsequent mobile HCI intervention: the "Virtual Cycling Coach" (VCC), an on-the-bike virtual coach, that is aware of its user's actions and context. To provide *in situ* support to cyclists on their bike in real contexts, it delivers coaching interventions in appropriate moments.

I thereby understand coaching "as a collaborative solution-focused, result-orientated and systematic process in which the coach facilitates the enhancement of life experience and goal attainment in the personal and/or professional life of normal, nonclinical clients" (Grant 2003). Existing meta-reviews on the effectiveness of coaching show that it has significant positive effects on performance/skills, well-being, coping, work attitudes, and goal-directed self-regulation (Theeboom, Beersma, and Vianen 2014). There is the subset of virtual coaching or e-coaching, characterised by using information and communication technologies as a means to facilitate coaching. In a meta-analysis for health care, coaching has been shown to improve outcomes in supporting and motivating chronically ill adolescents (Tornivuori et al. 2020). Another study on virtual coaching – including ones fully executed by systems through a set of pre-defined questions – produced comparable outcomes to conventional interpersonal coaching (Geissler et al. 2014). However, there are no studies so far that investigated a coaching approach in the domain of utilitarian cycling.

The chapter concludes with a critical reflection on the opportunities and limitations of providing *in situ* support for competence development through information and communication technology in the realm of utilitarian cycling.

The case studies presented herein were also part of the research project between the Media Lab at the Massachusetts Institute of Technology (M.I.T.) and the AIT Austrian Institute of Technology. Alexandra Millonig, Agnis Stibe, Ryan C.C. Chin, Stefan Seer, Katja

[1]The publication related to this is: *Wunsch, Matthias and Geraldine Fitzpatrick (2021) Complex Contexts and Subtle Actions: Design and Evaluation of a Virtual Coach for Utilitarian Cycling. In: Ardito C. et al. (eds) Human-Computer-Interaction – INTERACT 2021. INTERACT 2021. Lecture Notes in Computer Science, vol 12936. Springer, Cham.*

Schechtner, and Kent Larson have been involved in this project. Geraldine Fitzpatrick provided generous support and guidance for my academic development, writing and thinking. Most the design and research was conducted by me. I use the pronoun "we" to refer to activities where my colleagues contributed. The findings from the case studies have been published and presented at the conference INTERACT 2021.[1]*. This chapter is directly based on this publication. I also presented the design of the Wizard of Oz prototype at the Cycling@CHI workshop at ACM CHI 21.*

6.1 Case Study VI: Teaching and Coaching for Beginning Cyclists

The previous case studies as well as related work support the understanding that sufficient competencies are necessary for adopting cycling. People who are beginning to ride bicycles to fulfil their transportation needs are at the center of this study. To gain a better understanding of the experiences of those (novice) cyclists, I worked together with a local bike advocacy group in Vienna, Austria, that offers classes for beginning and for advanced cyclists. There, I could do field interviews with the cycling instructors and observe the courses they conducted. Furthermore, I worked with a cycling coach from the same region specialised in supporting his customers to learn cycling for utilitarian purposes. The work within this case study thus asked: *"What teaching and support methods are used in existing bicycle education and training settings?"* We did this to inform the design of the Virtual Cycling Coach, which is evaluated in the subsequent case study.

6.1.1 Methods

Empathetic participant observation is key for gaining knowledge about the experiences of people in this situation (Wright and McCarthy 2008). For this, I conducted one observation lasting for two hours in the beginner's class with five students, unstructured *in situ* ethnographic interviews with the students as well as *in situ* interviews with the three cycling instructors. I also conducted two observations in the advanced class, which, at that point had nine participants and two instructors, each lasting for one hour. The two cycling instructors – one being the same as the one in the beginner's class – were interviewed *in situ*. Field notes and memory protocols were used to record our observations and interviews.

In addition to the cycling classes and to gain insights into a more coaching-oriented approach, I had two 1.5 hour long expert interviews with the cycling coach. He furthermore provided video material demonstrating his coaching approach. Notes and the provided video material were used here as primary data.

Figure 6.1: Photo of cycling class at the advanced level. Source: Still image from the national television report "Wenn Frauen Radfahren lernen" via tvthek.orf.at

Analysis

Thematic analysis was used to identify and structure emerging themes regarding the experiences of urban cycling following the steps described in Chapter 3. The collected notes and descriptions where coded, analysed and structured by me together with a colleague[2] to produce the results described in below. Given the qualitative paradigm, our own subjectivity was part of that analysis process. Particularly, we had to reflect on our own knowledge about urban cycling, and how this was similar or different to our data. In reflection on and engaging with the data, we could emphasise with the experiences of urban cyclists we observed in the teaching settings.

6.1.2 Findings: Existing Support Strategies

Observing the cycling classes and doing the interviews with the instructors and the cycling coach offered many insights into how professional instructors teach and support cyclists. In this section, I will first outline the course structures and course curricula, also highlighting differences between the class setting, i.e. riding as a group guided by instructors, and the coaching setting, i.e. a one-on-one session between the novice cyclist and the coach. I will then outline the strategies for supporting learning experiences, framings, the use of feedback and motivational support, the students' agency and the role of reflection.

[2] Alexandra Millonig

Course Structures

The bike-advocacy group offered different classes for a beginner- and an advanced-level. The cycling coach made a similar distinction for the type of coaching he offered. At the beginner level, the emphasis was put on enabling students to do recreational cycling in traffic-free areas. At the advanced level, they were prepared to ride their bikes for everyday trips in an urban environment. The classes consisted of ten sessions, held weekly, each lasting for two hours. There were agreed upon meeting points and meeting times and the students had to enroll upfront. The number of students per class could go up to 20. As not all of them attended all sessions, some sessions had only five attendees. There were typically two cycling instructors present in each class session. In the one-on-one coaching setting, the coach had only one student for usually three to five sessions, each lasting for two hours and being typically about one to two weeks apart. The coach and his student agreed upon a suitable meeting point and time upfront. While the coach also offered training on a beginner and advanced level, the specific content of each session was tailored to the student's needs.

Training Content

The curriculum for the beginner level classes covered various exercises to practice basics of riding a bicycle, such as balancing, controlled steering and braking, riding along given paths, e.g., a straight line or around obstacles, shifting gears or viewing technique. At the advanced level, students practiced riding in more complex situations, such as riding on streets according to traffic laws, including right-of-way, signalling, turning at intersections, entering and exiting separated bike-infrastructure or interacting with motorists. In general, they were trained to ride in a defensive, aware and anticipatory way. In order to participate in this advanced level, students had to be able to handle their bicycle well enough to participate in the advanced level training, including being able to stop and start riding without falling over, braking sufficiently if necessary, and being physically capable of riding a bicycle for several kilometres.

Supported Learning Experiences

The classes at the beginner level took place in socially and spatially safe spaces. The novice cyclists were provided with an accepting, patient and open-minded social space where students did not have to feel ashamed when they had problems or failed to do certain exercises and "where it is okay, to learn cycling as an adult" (Instructor 1). These training sessions were conducted within recreational areas with no motorised traffic. For the cyclists this prevented feeling overwhelmed by the complexity of the surroundings. For beginners the physical and mental effort of controlling a bike, such as balancing, adjusting speed, pedalling also takes away mental capacity, with beginners often riding at low speeds and basically just trying not to fall. This mental depletion can reduce the cognitive capacity for coping with interacting in complex situations (also see Wierda and Brookhuis (1991) and Brisswalter, Collardeau, and René (2012)).

For the advanced level, the instructors or the coach selected routes that were appropriate to the current level of competencies of the student(s). The selection of these routes was done very deliberately, to provide the right sort of experience – or teachable moments – to the students. An example was riding within a lane with shared traffic, i.e. together with motorised vehicles and next to parked cars. The loud, heavy and fast-moving vehicles can be stress-inducing and typically result in negative emotional responses. I observed that defensively riding cyclists tended to ride at the very right side of the lane. However, if there are parking cars next to the lane this means riding within the "dooring zone", i.e. being in danger of colliding with a car door while it is opened. Hence, the intuitive response of the cyclists – riding on the very right side of the street to give way to faster moving traffic – resulted in a more dangerous situation for her. Coaching could help here by both pointing out the risk of opening doors when riding too close to parked cars and by offering reassurance that a cyclist can ride within the lane to have sufficient safety distances. However, giving such feedback in-the-moment was hardly possible for the instructors as the moving group and noisy surroundings did not provide an opportunity to do so.

Re-framing

Metaphors and re-framings were deliberately used, especially in the coaching sessions. For example, motorised vehicles were often perceived as dangerous and scary, resulting in an overall negative experience of cycling close to them. The coach would use phrases to re-frame this experience, for example: "Cars are easy. They are loud and fast, but you can predict them. They cannot move suddenly or change direction at once." Another example was fear, which is often experienced by novice cyclists. The coach would acknowledge that and frame it as a signal. His students should understand this signal as "telling them that something is not right", and how to act upon it. The instruction was to slow down or pull over and stop if one was scared. Beyond that, with their own behaviour and attitude towards cycling, the instructors and the coach acted as role models. They could convey a defensive, aware and anticipatory way of riding a bicycle and the joy and simplicity of doing so. In talking to their students, they also shared their attitude towards cycling in the city, with it being a sometimes challenging, but mostly a rewarding mode of transportation to them.

Feedback and Motivational Support

In the beginner's class, the instructors observed the students and provided feedback to them. This was possible as the students stayed mostly within a small physical area – typically not more than 30 meters away from the instructor. Critical verbal feedback such as "take care" or "that was not so good" was given when students acted in ways that could result in minor accidents or fall-overs. This was often followed up by advice, verbally and in most cases by example, i.e. the instructor demonstrating an exercise. More often than that, positive and reinforcing feedback was used such as "that was good" or "you are doing much better now than the last time". This was often followed-up with an instruction to keep doing this exercise or that the student would be now "ready for more". Besides that, the instructors of the class were also trying to keep the mood up and to keep their students motivated to keep trying and practising.

The advanced class also rode as a group in traffic, which made it difficult for the instructors to give feedback immediately. Even the coach, who typically only has one student to take care of, was challenged by the lack of immediacy. This is comparable to the difficulties reported for the bike buddy rides in Case Study III. The cycling coach was therefore at the time of the second interview experimenting with providing annotated video recordings of the rides with his students. By providing those, he hoped to further help them to analyse and reflect upon the ride at a later point.

Agency

During the classes, I observed that an instructor was typically riding upfront and the group of students would follow her as a group. Therefore, the individual students mostly tried to follow the person riding in front of them and acted as a member of the group. They often exercised the same acts as the cyclists in front of them. It is likely that due to this setup, the agency of the individuals, i.e. their awareness and decision making, was less considerate than when riding on their own. In contrast, in the one-on-one coaching sessions, the student typically rode ahead with the coach riding behind them. This created a situation where learners could not rely on someone else to guide their actions and had to take more responsibility for their decisions.

The coach also highlighted the need "to read" traffic situations, that is the capability to anticipate actions of other cyclists, motorists and pedestrians. It also included the ability to see what the built infrastructure enables and requires from the cyclist, to detect possible sources of danger, and to ride as effortless and safe as possible. With this he emphasised that cyclists need to see themselves as being in control of their situation.

Reflection

During the rides, the coach would stop whenever he "felt it to be appropriate or necessary", to discuss and give feedback on what just happened. This reflection-on-action (Schön 1983) is a main instrument in his teaching approach and according to him it should happen as often and as immediate as possible to create a strong learning experience for the student. He also used photos from the ride with the students to support them re-living the experience and thereby reflecting on and learning from it. The time between the individual sessions – one to two weeks – was meant to help students reflect and to let the learning "sink in".

Teaching Limitations

In both the class and one-on-one coaching settings providing feedback in-the-moment while being in traffic was difficult. This is both grounded in my observations and in statements by the instructors. In classes, the instructors had to wait for the whole group to come to a safe stop before giving feedback. This delay made the feedback hard to understand, as the situation it was referring to (1) had often happened minutes before and (2) was experienced differently dependent on each cyclist's position within the group. Teachable moments also typically occurred for individuals and not the entire group. Hence, even though the group allowed more students to practice at the same time, the lack of intermediate feedback on an individual's experience likely resulted in a less effective learning setup.

Another limitation was in how the teaching could be tailored to the individual student. The one-on-one coaching setting offered more personalised training to students, which was not possible in the classes. In the latter, the needs and problems could vary substantially between students. For example, a set of students had a driver's licence and were therefore familiar with traffic rules and signs, but struggled with handling the bike and fear from motorised vehicles. Within the same class, other students were handling the bicycle proficiently but failed to follow the traffic signs and general traffic rules. Another aspect of this was the spatial context: In the one-on-one setting, the coach tried to ride in areas that his student would be riding in the future as well. This was not possible for the classes. Therefore, the students could typically not practice riding where they lived or riding a route they would need in their everyday routines. This points to a more general limitation of the transferability of the learned skills into different contexts. For example, one participant in the class reported that she was taking it already for the second time and did really enjoy it, but did not feel confident enough yet to ride in the area she lived in.

Summary and Implications for Design

Working together with the cycling instructors and cycling coach provided us with valuable insights into the range of competencies needed for cycling, how those competencies were taught, and what the challenges of doing so included. As for the latter, we found that it could be difficult for the instructors or the coach to provide immediate feedback. Participating in the classes or having a one-on-one coaching session involved a substantial amount of coordination, i.e. meeting at a time and place. While the class setup enabled to teach multiple students at the same time, thereby scaling the idea up to reach more people, riding as a group reduced the agency of the students in it. These findings point towards an opportunity for ICT to offer support that is focused on the moment of cycling, and could potentially be easily accessible and scale-able in the future. I investigated this approach in the subsequent case study.

6.2 Case Study VII: Virtual Cycling Coach

Based on the case study presented above, we asked the question: *"Can cyclists be meaningfully supported in-the-moment using information and communication technology?"* To answer this, we designed the Virtual Cycling Coach (VCC) – a system that acts as a virtual coach on the bike with the goal of supporting the development of a general urban cycling competence. We follow the definition outlined by Siewiorek (2012) and Lete, Beristain, and García-Alonso (2020): "A virtual coach system is an always-attentive personalized system that continuously monitors user's activity and surroundings and delivers interventions – that is, intentional messages – in the appropriate moment." The VCC is designed to explicitly create a learning and practicing opportunity out of an occurring experience or teachable moment. The concept of a virtual coach tackles some of the limitations found in the existing teaching approaches outlined above: As it is always present, a virtual coach can give immediate feedback in a teachable moment and do so within a spatial context most relevant to a user. It also scales up the tailored approach found by the cycling coach.

This represents a mostly unexplored application domain. Sörös, Daiber, and Weller (2013) proposed a comparable context-aware coaching system for cyclists using Google Glass. They developed a prototype that included heads-up visual feedback and hands-free voice control. However, this was not evaluated in real cycling situations.

6.2.1 Design

Monitoring User's Actions and Context-Awareness

The design of a virtual coach was chosen to enable individualised, in-the-moment and on-the-bicycle support for its users. For this, the VCC has to have the capability to "understand" both the context of the rider as well as her actions within it, with no input from a user. Building a system capable of such an awareness was beyond the scope and resources of the research project. To avoid limiting the design by that, we used a Wizard-of-Oz-prototype described below.

Interaction Design

The Virtual Cycling Coach uses an audio-based voice user interface (VUI), as its ubiquitous use in navigation systems and prior studies with cyclists repeatedly reported this as being the preferred interaction mode (Lee et al. 2010; Marshall, Dancu, and Mueller 2016; Matviienko, Ananthanarayan, El Ali, et al. 2019; Rowland et al. 2009). For the VUI of the Wizard-of-Oz-prototype, I used pre-recorded audio messages. It was thus not possible to directly talk with the study participants. Communication towards them was limited to selecting and then playing back an audio message from a predefined set of messages, e.g., "Good", or "Try to do this better the next time."

Coaching Interventions of the Virtual Cycling Coach

The VCC should offer support similar to the advanced level training described above, i.e. persons that can balance, steer and control a bicycle and know essential traffic rules. The curriculum was created for typical situations in which cyclists felt they needed reassurance. Our knowledge on which situations these are was grounded in the study on existing coaching and teaching settings (CS VI). Additionally, guidelines for cyclists from Boston (MA), educational material from bike advocacy groups[3] and textbooks used for cycling education in primary schools in Austria have been used as expert input to the design of individual interventions. Examples of the interventions are shown in Table 6.1.

Coaching Strategy

The coaching interventions target the "manoeuvring level" of cycling (Wierda and Brookhuis 1991), that includes e.g., decisions about the course and tactics in traffic, selecting appropriate speeds in a specific situation or interactions with other traffic participants. They span from easy to more challenging exercises, to allow the VCC to scaffold learning by providing exercises that are challenging, but not too challenging (Slovák, Frauenberger, and Fitzpatrick 2017). A session could start with riding on a quiet street and looking back or giving hand signals. Later on, a session could involve more complex contexts and be combined with more difficult exercises, e.g., doing a left turn on a busy street intersection. An excerpt of the curriculum developed for the VCC is shown in Table 6.1.

Similar to the professional cycling coach, the VCC should promote an overall defensive, aware and anticipatory way of cycling. The messages should convey this approach of cycling while also including questions to provoke reflection-in-action (Schön 1983). For example, while riding in traffic the VCC would prompt awareness and anticipation, but also prompt reflection with messages such as "What can you anticipate? Hear! Look around!" Other messages were "Think! What could be a danger to you? How can you react to that?" or "Do you think that the current distance to the parked cars is sufficient?" This approach also allowed us to include a set of generic messages. Those enable the VCC to stimulate reflection beyond pre-defined situations.

6.2.2 Methods

The prototype of the Virtual Cycling Coach was qualitatively evaluated to study the experiences created by using it in a real-world scenario to see if the coaching reflection-in-action approach could be achieved. Prior to conducting this study, a formal ethical review by the Committee on the Use of Humans as Experimental Subjects (COUHES) at the Massachusetts Institute of Technology (MIT) has been completed. Parts of the documentation for this review and the consent form are included in the appendix to Chapter 6. The evaluation was conducted in two subsequent rounds, in Greater Boston, MA, US and Vienna, Austria. Both cities have seen a steady increase in bicycle ridership.[4] Both also do provide dedicated cycling infrastructure, however, it is mostly retrofitted to existing streets resulting in complex negotiations with other road users, particularly at intersections.

[3] `http://www.bikeleague.org/ridesmart`, last accessed at Feb 2021

[4] `https://www.nast.at/leistungsspektrum/verkehrsmanagement-und-verkehrssteuerung/verkehrsdaten/`, `https://www.cambridgema.gov/CDD/Transportation/gettingaroundcambridge/bikesincambridge/biketrends`, both last accessed at Feb 2021

Table 6.1: Excerpt from the curriculum for the Virtual Cycling Coach

Coaching intervention	**Triggers and simulated inputs**	**Voice interface output**
Bicycle handling techniques, e.g., looking back during riding, accelerating and braking precisely	Riding in a safe space (e.g., no motorised vehicles, little complexity). Simulated input: geolocation, object detection	"Now speed up a little and try to brake as hard as you can." "Watching out is crucial for cycling. Now try to ride in a straight line while looking behind you from time to time."
Raise awareness in traffic: Prompt awareness and anticipation; trigger reflection one's own awareness	When entering more crowded context, e.g., entering an area with motorised traffic. Simulated input: geolocation, object detection	"What can you anticipate? Hear! Look around!" and "Think! What could be a danger to you? How can you react to that?"
Re-framing negative emotions as helpful indicator: Using fear as a signal; practicing slowing down and stopping as a behavioural strategy to cope with fear	When in a crowded traffic situation. Simulated input: object detection, noise levels	"I want you to know: Fear is good! It tells you that something might be wrong." "If you are scared slow down or stop."
One's own actions in traffic: Teaching safe practices for right and left turns	Participant is approaching an intersection. Simulated input: geolocation	"Let's practice right turns. The sequence is: Look back, signal, turn if possible."
Reassurance: Provide support and reassurance to take space on the road to have sufficient safety distances	Participant has been riding too close to a pedestrian, parked vehicle or a physical obstacle. Simulated input: object detection and distance measurements	"Take your space, there has to be room for error." "Try to have more safety distance around you or slow down."
Riding next to parked cars / dooring prevention: Reflect on how they ride next to parked cars and the danger of opening doors.	Participant riding on a street next to parked vehicles with insufficient distance (under 1.2m). Simulated input: same as above	"Let us focus on riding next to the parked cars. Do you think that the current distance is sufficient?" "Good, you are currently riding with enough distance to the parked cars."
Provide situated, in-the-moment feedback to reinforce desired actions	Participant actively follows instruction by VCC. Simulated input: comparison between current state and desired state	"Good" "Good, let's repeat this."
Provide critical feedback on an undesired action of a participant	Participant rides close to a pedestrian. Participant did not anticipate other vehicles	"Try to do this better the next time."

Wizard of Oz Prototype

Wizard of Oz prototypes have a long standing tradition in HCI research, with early studies on simulating voice based text input dating back to the early 1980s (Kelley 1984). Broadly defined, such a prototype "... requires two machines linked together, one for the subject and one for the experimenter. In this implementation the experimenter (the 'Wizard'), pretending to be a computer, types in complete replies to user queries or presses function keys to which common messages have been assigned" (Green and Wei-Haas 1985). Related examples for using this prototyping method are studies on location aware applications (e.g., Li, Hong, and J. A. Landay 2007) or explorations of interactions within automated motorised vehicles (e.g., Habibovic et al. 2016).

However, in the context of cycling, only one other published study has used this prototyping approach. In it, Rittenbruch et al. (2020) explored on-bicycle notifications for hazard warnings, which included situations like pedestrians on a collision course, a tree branch on a cycle path with limited options to circumvent it, and cars passing from behind. For evaluating their early design, they did a qualitative evaluation with 12 participants in a cycling simulator. To date there is no other study where Wizard of Oz prototypes for cycling have been used in the wild.

The goal of the prototype was to simulate the capability to "understand" both the context of the rider as well as her actions within it. The prototype therefore consisted of a software client that a user interacted with and a software controller that was used by "the Wizard" to control the client. This gave the wizard the opportunity to provide the necessary input, i.e. the understanding of the context and the riders actions. For the evaluation of the Virtual Cycling Coach, both client and controller were implemented as web-applications that were optimised for internet-connected smartphones. A web-server facilitated the communication between controller and client as shown in Figure 6.2. A similar setup with a hardware extended client on the bicycle was used by Rittenbruch et al. (2020).

The later version of the prototype included a small GUI on a touchscreen which was also part of the client and it displayed the current message. However, in the study participants neither needed to look at the display nor interact with it. The output of the VCC was based on the context and actions of cyclists and triggered by "the wizard" using the controller GUI shown in Figure 6.3.

To balance the real world context with safety concerns, several design decisions were taken: (1) Distractions from traffic were minimised by not having any reliance on a graphical user interface during use. (2) Mental workload was kept low by having breaks between voice messages from the system. (3) The virtual coach application did not include specific guidance. For example, there were no instructions such as "turn left now". This was done to keep the VCC more generic and to promote the agency of the cyclists using the VCC.

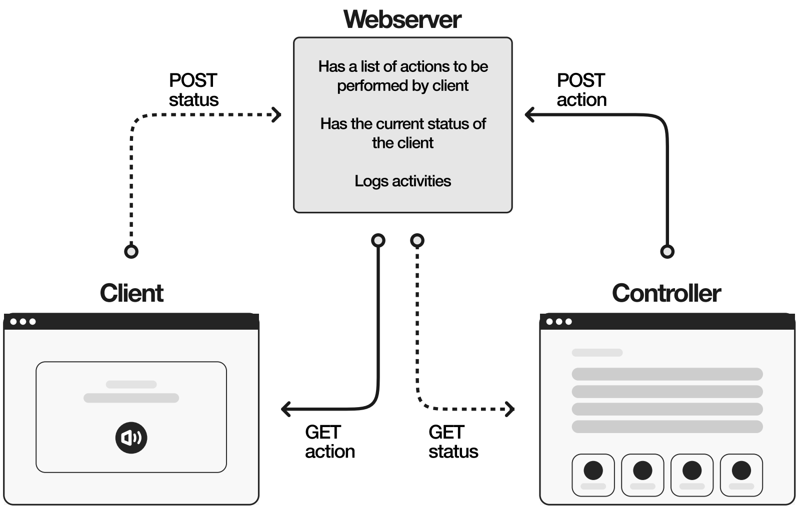


Figure 6.2: Technical setup for the prototype showing the HTTP calls that communicate between client, controller and web server. *Actions* refer to the output to be performed by the client, *status* is the currently performed action by the client.

Evaluation

The VCC was evaluated in two rounds. In the first, I was following the study participants by bicycle. In the second evaluation round, I stayed at the point of origin and the study participants rode on their own. The sessions using the VCC lasted between 20 to 45 minutes. Each session began with an introduction to the concept of the Virtual Cycling Coach and a short semi-structured interview to assess the participant's level of experience and confidence in urban cycling. Depending on those, we adjusted the time spent with exercises of the coaching curriculum to the participant. For example, a novice cyclist was given all basic exercises and did those in a traffic-free or low-traffic area, whereas an experienced cyclist started with riding in denser traffic right from the beginning.

Participants were video- and audio-recorded using cameras mounted on the bicycle. They were also asked to think aloud to collect data on thoughts that occur in-the-moment. Observational material was collected as well by me and my colleagues that were present during the sessions, including the choices of the participant such as the speed, the distance to other vehicles or pedestrians as well as their overall handling of the bike. Participants did not know from the start of the session that the output of the VCC was directly controlled by me.

First Evaluation Round: Cambridge, MA, United States

Fifteen adults were recruited in the Greater Boston area (MA, USA) using mailing lists from the Massachusetts Institute of Technology (MIT). Six of the participants were MIT students. Seven participants were female, eight were male, their age ranged from early

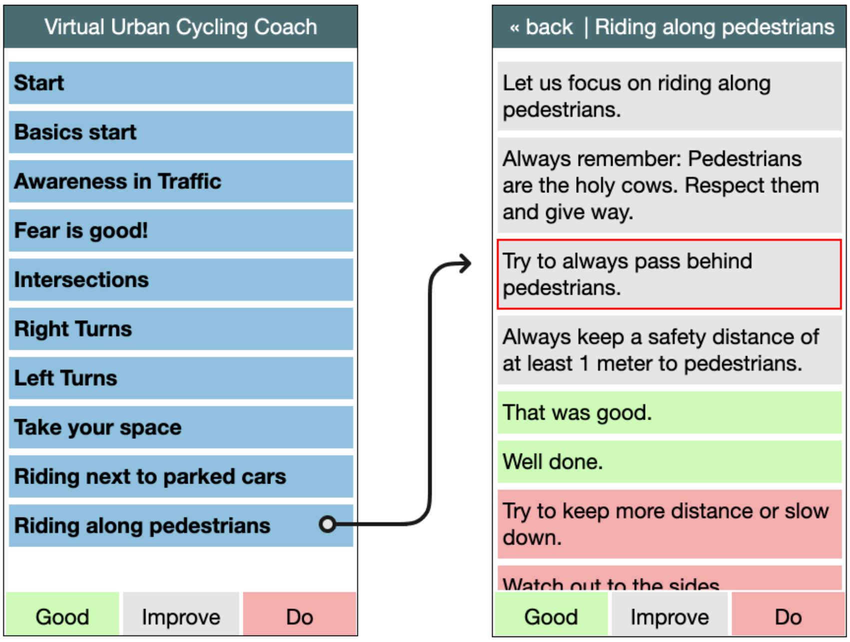


Figure 6.3: Prototype controller UI: *Left:* Selection of the coaching exercise. *Right:* Audio messages to be played to the cyclist. Different background colors were used to distinguish neutral messages, positive feedback and critical feedback. The red border indicated the currently playing message.

20 to early 60. The evaluation study took place in Cambridge (MA, USA) over a period of two weeks.

In this round, the participants put a smartphone with the VCC client in a pocket and could hear the VCC via earphones they wore.[5] I would follow the participants on a bicycle, typically riding 5 to 30 meters behind them, partially instructing them where to go. To control the prototype, I used a handle bar mounted smartphone running the controller. This approach ensured that I got a very good understanding of the context and actions of the participant. However, a drawback of this approach was the distraction while riding myself. I tried to counteract this by optimising the controller for this mobile use with large touch areas and easy to read text as shown in Figure 6.3.

A voice recorder with a clip-on microphone was given to the participants to record better quality audio of them thinking aloud during the rides and when talking with me or my colleagues. I could use traffic related stops (e.g., at red lights, stop signs, etc.) to gather *in situ* feedback from participants about their experience using the VCC. The

[5]The earphones did not block outside noise. The volume of the VCC was set to a level so that participants were able to hear traffic while the VCC was talking to them. This setup with a low audio volume was chosen for safety reasons and participants did not find it distracting. However, at times they could not hear messages from the VCC.

sessions were recorded using two GoPro action cameras, one on the handlebar recording the participant and one on the participant's helmet. In the second week of the study, we added a third camera which was mounted on my bike to record the participant with more distance from behind. While starting the video, a live timecode from the VCC server was shown into the camera for syncing with the log-files of the VCC stored at the server. The log-files – containing when which message was said to the participant – were later combined with the video and audio recordings in a single video file used for analysis.

Follow-up interviews were conducted three months after the sessions. Those were semi-structured open-question interviews reflecting on the experience of using the VCC and cycling thereafter. Those follow-up interviews were conducted via Skype or phone and lasted between 12 and 30 minutes. We were able to conduct those interviews with all but one of the 15 participants of this evaluation round.

Second Evaluation Round: Vienna, Austria The main reason to conduct this second evaluation round was to examine if an observer effect had been introduced due to me – the researcher – riding behind participants. We changed the set up to have the wizard control the prototype more remotely. Therefore, the VCC client smartphone was put in a casing, mounted on a bicycle's handlebar. As shown in Figure 6.4, the casing housed a speaker, thereby eliminating the need for study participants to wear earphones and the need to synchronise the log-files with the videos for analysis as the VCC messages were recorded on video. A 360° camera was mounted on top of the casing to record the sessions. The casing also included a second smartphone that would live-stream a video to me showing the current location and environment. This eliminated the need to follow the study participants, as the VCC could now be controlled remotely while staying at the meeting point. This setup allowed me to stay in the background and control the prototype without being in any danger. However, a drawback of this prototype setup is the limited amount of information, i.e. just having the field of view from the live-video feed to gather an understanding of the context and the actions of the cyclist. Time-lag and unstable video feeds could be problems but were mitigated in this study by staying in areas with fast and reliable LTE connections.

Ten adults living in Vienna were recruited using university mailing lists and via social media. Two of the participants were university students. Eight participants were female, two were male, age ranged between 20 and 40 years. The evaluation study took place in Vienna over a period of eight weeks. The participants were instructed to ride for about 20 minutes on a route of their choice. They did not need to ride along any particular route.

Sample

The overall study sample across both rounds included 15 women and 10 men. 12 participants reported public transport as their main mode of transportation, 11 reported bicycling, one was primarily walking, and one primarily used her car. As for their experience with urban cycling, one participant had none, 13 participants had some

Figure 6.4: Hardware iteration of the Virtual Cycling Coach used in the second evaluation round: Mounted on the handlebar, the casing housed a front-facing camera that live-streamed a video feed to the controlling researcher (the wizard), a smartphone with an attached speaker for outputs of the audio interface, and a 360° camera on top for recording the session.

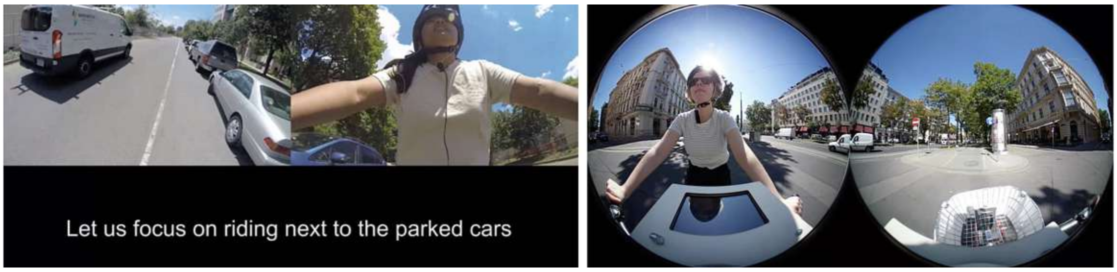


Figure 6.5: Combined video and log data used for analysis of the rides using the Virtual Cycling Coach (VCC) from the first evaluation round (left). 360° video from second evaluation round (right).

experience – i.e. they rode a bike a few times per year in the city – and 11 had substantial experience in urban cycling.

Analysis

The collected data ranged from interview recordings, field notes and video-recordings with the participants riding and thinking aloud as shown in Figure 6.5. The latter offered detailed, contextualised information on the experiences of the study participants which were annotated along with the transcripts. The data was partially transcribed and summed up by me together with two project collaborators. A thematic analysis was used to provide a detailed account within the data, following the procedure outlined in Chapter 3. The coding of the data was also informed by the exploratory studies, however unexpected themes that emerged from the data have been taken into account as well.

6.2.3 Findings: Qualitative Evaluation of the Virtual Cycling Coach

We conducted this study in two evaluation rounds to assess if an observer effect was present. In the first round, I was riding behind the participants and following them, while in the second round I was not present during the rides. In the analysis of the gathered data there was no theme that pointed towards an observer effect within the first evaluation round.

Overall, using the Virtual Cycling Coach was appreciated by the study participants. They found the idea interesting and saw value in receiving in-the-moment feedback. In line with existing research on interaction design for cycling, participants generally liked the audio-based voice user interface (VUI). But there were instances, particularly when riding in loud traffic, where instructions could become difficult to hear. Failures of the system in general, such as providing an inappropriate message, where seen as flaws of the prototypical setup by participants within the evaluation study.

Participating in the VCC evaluation study already affected the anticipation of the cycling experience. The bicycle ride was about “learning”, “coaching”, and “support”, thereby changing the framing of cycling from a generic everyday experience to a deliberate learning experience. As creating a learning and practising opportunity out of an occurring experience or teachable moment, in-the-moment guidance was a prominent feature – allowing participants to gain procedural knowledge. For example, to teach a turn sequence when a participant approached an intersection, the VCC would provide this message: “Let us practise right turns. The sequence is: Look back, signal, turn if possible.” Participants regarded exercises such as this one as helpful guidance in-the-moment, something that made them aware of how to interact within traffic. In line with this, using the VCC was generally perceived as a learning experience.

Participants were often prompted by the VCC to repeat exercises and those could take place in several different locations. For example, the VCC would prompt them to focus on the viewing technique and signalling whenever participants made turns at intersections, or would prompt them to keep enough safety distance to pedestrians as soon as there were interactions with those. Repetition also resulted in a strong memory of the actual coaching messages: Even in the follow-up interviews, which took place three months after the VCC sessions, participants could recall the VCC’s messages and often even the exact wording of those. Repetition and reinforcement in the use of the VCC added a quality of learning to the overall cycling experience, similar to the existing non-technological approaches outlined in Section 6.1.

Furthermore, the VCC was designed to adjust the learning experience to its users, e.g., by doing certain exercises in safe or less complex environments. Thus, the rides and exercises were at a suitable level in relation to the competencies of the participant, that is being not too easy but also not too hard (Slovák, Frauenberger, and Fitzpatrick 2017). A typical session therefore started in areas with little or no traffic from motorised vehicles, as shown in Figure 6.6. We could observe how this helped participants develop competencies like looking back while riding or riding with one hand on the handlebar to signal turns. “I didn't look back much because I was scared. I thought that I would lose control. But after doing it a few times in a safe environment it was fine." (Judd[6] | follow-up interview)

Figure 6.6: Start of a session with the VCC in the first evaluation round. The participant is riding in an area without motorised vehicles to reduce overall complexity of the context.

Effective Feedback and Reassurance

Feedback from the Virtual Cycling Coach was given repeatedly based on the quality of a participant's actions. Less experienced cyclists noted that this was helpful for them to understand what is the right or safe thing to do. This reduced the feeling of uncertainty for novice cyclists. Deliberately riding and reflecting on cycling in urban traffic also led participants to ask themselves specific questions. Those were mostly legal questions regarding the rules of traffic that emerged during the sessions or related to best practices, e.g., in what areas cycling is allowed, how much space a cyclist is allowed to take or different types of signalling turns by hand. Having the external support structure during the ride can provide answers to such specific questions.

The more experienced cyclists expressed that the VCC was a way to reassure them that they were right with their own thinking or, in other words, that the strategies they had created based on experience were right. "I think of some of this confusion what the best practices are. [. . .] There are things to know like what are the legal obligations and what is the safest." (John | during session) An instance for this was how to interact with motorised vehicles in tight spaces, where many cyclists had a feeling that they were blocking cars and supposed to ride on the very right side of the road. The focus on how and why to act in a certain way further reduced uncertainty and increased confidence in acting according to the guidelines used to inform the curriculum. The VCC reassured them that they should always keep a safety distance of one meter to parked cars, often meaning that they had to use the full lane. "I remember particularly [. . .] needing to make sure that you take over the road. If there is a road that you are sharing with a car. So that you don't feel shy." (Sara | follow-up interview)

During these rides the participants often raised additional questions on laws, best practices and guidance. This indicates that the VCC promoted the engagement with "how" one was

[6] For this case study we used cover names for all participants.

cycling in the given urban environment. Participants also developed a more pronounced view of themselves within urban traffic. The language used to express that points at a strong feeling of agency for their actions and that they view those actions and themselves situated within traffic. Using the VCC is by design a reflective activity. This might result in developing a more pronounced outside view of seeing one's actions from the perspective of others as well. "And still, everyday things! Thinking about: where are my relations to other cyclists, vehicles? Am I being predictable, visible? It's something that it [the VCC session] certainly made me aware of: my physical surroundings and how I fit into those and to ensuring my own safety." (John | follow-up interview)

Reflection

Technology makes it possible to give in-the-moment feedback as well as to prompt reflection-in-action, aspects that the cycling instructors and the coaches found to be difficult (Case Study VI). Participants knew upfront that the aim of this study was to support them in urban cycling by setting up an explicit learning structure, with the participant being in the role of the learner and the VCC as well as the present researcher taking up the role as coach. Even without the Virtual Cycling Coach being active, the very presence of this structure led to reflection-in-action. Participants said they were more aware of how they were riding and that they acted more deliberately, knowing that their actions were observed. So, with and without the VCC being active, a reflection-in-action was present. Our analysis did not reveal differences between the two evaluation rounds that would indicate reflection happening due to an observer-effect.

The messages from the Virtual Cycling Coach were mostly understood by participants as advice on what to do, rather than prompts for reflection-in-action. However, here, it is of relevance how specific the VCC messages are. A message can contain specific advice such as: "Always keep a safety distance of at least one meter to pedestrians." This was expected by the participants. But the VCC could also prompt a participant with general and unspecific messages such as: "Think! What could be a danger to you? How can you react to that?" We found that those did help to further trigger reflection, with the first step being a participant becoming more aware about what to reflect on in the specific moment.

The following description of a segment from an evaluation session highlights the role of reflection. The participant was riding in an area with other cyclists and pedestrians and no motorised traffic. The VCC said: "Let us practice some basics." The participant was riding at a low speed while thinking aloud: "Make sure you don't get in the way of other bikers." Then, the VCC said "Watching out is crucial for cycling. Now try to ride in a straight line while looking behind you from time to time." This exercise was meant to deliberately practice looking back without losing control or balance. The participant was then trying to ride in a straight line while looking back, which at first he did not achieve. While doing so, he was thinking aloud: "Ok, the straight line, that's difficult, because you don't really know where you are going." Now, another cyclist and a pedestrian entered the area and passed close by. The participant continued thinking aloud: "Watch out for this biker and this person. But let's try it again. Let's try it again. Looking back, looking forward. That one went well. So after about three times it got a lot better." Repeating the exercise improved his ability to ride straight. Here, the previously established reflection process made the participant continuously improve his actions without the VCC intervening in any particular moment.

Development of Competencies

With coaching being an essential aspect of the VCC it does not come as a surprise that a theme of developing competencies is a result of interacting with it. Especially in the follow-up interviews participants reported a rise of their overall awareness during urban cycling. They were supported by the VCC to cycle in a defensive, aware, and anticipatory way. The Virtual Cycling Coach also helped to develop particular competencies and change specific aspects of how participants rode within the city. Those competencies were directly related to the curriculum of the VCC, for example instructions and feedback on riding along pedestrians or viewing technique. "I felt better checking for cars behind me as we kept biking. That was a helpful one." (Macy | follow-up interview) "[I] also remember [the VCC] telling me to look around occasionally. Which I've been doing, but I try to be a little more aware of how I get information. When there is not much traffic I still usually rely on my ears [. . .] but I am trying to make a more conscious effort to pay attention." (Anna | follow-up interview)

We included regular cyclists in the evaluation to uncover differences between them and less experienced cyclists. From those experienced cyclists, two did mention in the follow-up interviews that the VCC experience did not have had any effects on their competencies or behaviours. Other experienced cyclists reported that using the VCC had more relevance to them than they initially expected. The *in situ* approach of the VCC made them aware on aspects of cycling that they had either not considered before or had not embedded in their cycling routines yet. "I've had a lot of experience cycling before. But there were some things that I took away from it – that have actually stayed with me as I am cycling. Kind of remembering some of the instructions, you know, look back when I am turning right and things like that. So in a kind of surprising way I am remembering it even though I didn't think I would get much out of it back at that time." (Sam | follow-up interview)

6.3 Discussion: *In Situ* Interventions

We used a prototype that simulates understanding of context and actions of users and is able to provide relevant interventions in-the-moment and on-the-bicycle. Our findings show that the tight coupling between real experiences of users and the interventions by the VCC enabled meaningful learning and reflection. Compared to the Virtual Bike Tutorial in Case Study II, the approach shown in this case study offered a more useful and explicit learning experience to the participants.

6.3.1 Technology for Automatic vs. Reflective Actions

In the observations within Case Study VI, the students were able to ride a bicycle and did so in the contexts I observed them. This required not just the skill of controlling the bicycle, but many more cognitive tasks, e.g., understanding the context, predicting the paths of pedestrians, other cyclists and vehicles around oneself, applying knowledge on traffic laws. Those are constantly required and need fast responses. ICT can therein act in three ways: First, by blending in and supporting such fast, intuitive responses, e.g., by providing audio-visual or haptic cues for navigation, warnings, or an efficient speed (Dancu, Franjcic, and Fjeld 2014; Matviienko, Ananthanarayan, El Ali, et al. 2019; Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. 2018; Andres et al. 2019); Second, by deliberately prompting reflection on one's action to create learning experiences as shown with the Virtual Cycling Coach; Third, by being a distraction, something not relevant for the intermediate act of cycling, e.g., texting or entering a route destination on a smartphone while riding.

While the latter topic of technology as distraction is out of scope for this thesis, the former two point towards different roles of technology and goals for its design. On the one hand, there is design for an intuitive use and supporting existing actions. This is in line with established practices in user experience design (D. Norman 2013; Krug 2014). On the other hand, there are designs intended to trigger reflection and deliberate thinking. While this was explored here as a means to create learning experiences, another example can be found e.g., in apps and systems to support digital wellbeing (Monge Roffarello and De Russis 2019). A system such as the VCC would thus likely be used as part of a deliberate effort to improve one's cycling competencies.

6.3.2 Technological Limitations

Technologically, there is currently no system capable of understanding traffic contexts, human actions and human experiences, as simulated in the last case study, especially not one that could be fitted and used on a bicycle. Resorting to safe spaces like a cycling simulator in a research lab would be a way to study a system in a more controlled and safe environment. However, this would not generate comparable realistic experiences (Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. 2018). The Wizard-of-Oz prototype, however, did sufficiently simulate the system and allowed us to study the interplay between real contexts, the users' in-the-moment actions, and their experiences. As there are fast advancements in the field of autonomous systems (Harel, Marron, and Sifakis 2020), especially regarding a system's capability for understanding contexts, I anticipate that the technology needed for implementing the VCC will eventually be available on a bicycle. Our insights are useful as they can help inform the design of such systems, as has been the case in the past, e.g., for studying speech input using Wizard of Oz prototypes (Kelley 1984; Green and Wei-Haas 1985).

6.3.3 Being the Wizard

Reflecting on my role as the wizard, controlling the prototype helped to foster empathy towards the emotional and cognitive experiences of cyclists in realistic scenarios. Being the wizard, I had to constantly plan to trigger suitable messages. Thus, it became quickly apparent if a message was useful. Furthermore, being the wizard helped to uncover patterns for triggering messages. For example, when approaching intersections, exercises such as "signalling" or "raise your awareness and anticipation" were always suitable. Such insights can then inform technology design, as those triggers can be rather easily automated based on geo-location data. The selection of exercises and feedback was also grounded in my assessment of the participants' actions. However, automating this assessment on what could be appropriate exercises and how participants are doing them seems like a substantial technological challenge.

6.3.4 Implications for Design

The VCC could be hard to use in loud environments. Future work using voice user interfaces on bicycles should therefore offer a way for users to easily change the playback volume. Failures of the VCC in this case study were seen as problems with the prototype. However, future work could explore the trust between riders and such a coaching system and how it is affected by failures. Similar designs for support systems in real settings could also be improved by adding turn-by-turn navigation. And the other way around, bicycle navigation systems could benefit from a VCC, i.e. by guiding novice cyclists to traffic free areas or offering a routing suitable for the cyclists current level of experience and competence. This could help to reduce the mental load of its user, and would likely be anyway in line with preferences of inexperienced cyclists for potentially slower routes if they offer a more pleasant experience (Crist et al. 2018; Stinson and Bhat 2005).

A future approach might be to always offer a virtual coach. This could extend existing contexts with a learning opportunity, i.e. by being always present if a person wants to have some support or feedback in everyday settings, similar to existing advanced driver assistance systems. This would allow the VCC to provide coaching interventions over an extended period of time and when suitable situations and teachable moments occur, as these moments produce the reported processes of learning and reflection-in-action. This could also be the basis of a co-riding experience, that is, cooperation between the rider and the system as has been explored recently by Andres et al. (2019).

6.3.5 Limitations

With the two rounds for evaluating the VCC we have also seen limitations of the system compared to human interaction. Compared to real cycling instructors or coaches, the VCC is lacking the flexibility and capability to react to every event in some form. It also lacks the depth of the emotional support possible in communication between humans. For example, Füssl and Haupt (2016) found different strategies of coping with fear through qualitative interviews with cyclists. The VCC could not adjust to such strategies. It was designed to act based on a cyclist's actions and the environment, whereas a human coach could have a conversation to uncover and react to those coping strategies. However, our findings show that the VCC can create comparable learning experiences and reflection. A real system could very well complement, rather than replace, existing class or coaching settings. This is very similar to the use of virtual coaches e.g., in health care, where they are deployed in addition to conventional care (Lete, Beristain, and García-Alonso 2020; Nussbaum et al. 2019). Beyond the domain of health our work can also inform research in care for elderly, social-emotional-learning, or on-the-job coaching.

6.4 Chapter Summary

By studying professional cycling instructors conducting their classes, we uncovered how novice cyclists are taught to develop their cycling competencies. We designed and built a prototype of a Virtual Cycling Coach, with its evaluation showing that it can be a meaningful support that can generate similar processes to existing teaching settings. The VCC can enable a deliberate learning experience, provide effective immediate feedback and reassurance, prompt reflection and support the development of competencies. These findings have implications for similar designs and the development of mobile applications with dependencies to both context of use and actions of users.

CHAPTER 7

Human-Computer-Interaction in Utilitarian Cycling Framework

The technology interventions of the case studies were designed to probe into ways of using information and communication technologies to provide meaningful support to cyclists. They also show that cycling can be understood from different angles, e.g., cycling as a choice that is influenced by motivation and confidence, or cycling as a practice involving competences, and cycling as an activity embedded in a social and physical context with the built infrastructure being of key importance. This leads to the question of how to understand the role of ICT in cycling. Where are ICT for promoting the uptake of cycling situated? How are they connected to existing practices? There is currently a lack of theoretical work to structure the insights from my case studies for research and design of information and communication technology for utilitarian cycling.

To address this gap, I introduce a conceptual framework. Maxwell (2008) defines such a framework as a "system of concepts, assumptions, expectations, beliefs, and theories that supports and informs your research." I constructed this framework based on prior research, my own research, and my own experiences to have a coherent structure that provides a scaffolding for thinking about information and communication technology for cycling.

Grounded in the view of cycling as a social practice, I show how ICT can be added to an existing practice, thus presenting a view on technology for utilitarian cycling that remains highly contextualised and tightly connected to in-the-wild practices. I draw from insights of my case studies and existing literature to establish the framework. At its core is the view that utilitarian cycling can be understood as a practice that is itself a composition of smaller sub-practices, each of which consists of a dynamic interplay between material things, competences, and meanings. In this chapter I first lay out the structure and theoretical ideas of the framework. Subsequently, I situate my case studies and related work within it.

7.1 Towards A Theoretical Understanding of Utilitarian Cycling for HCI

For this framework to be useful, it has to bring together an understanding for the use of information and communication technology and utilitarian cycling. The former is grounded in HCI research, which itself is a broad field. As outlined by Bødker (2015), HCI was originally concerned with humans "as a subject to be studied through rigid guidelines, formal methods, and systematic testing" (ibid.) with its origin in human factors research. Later on, a shift towards understanding humans as actors, typically in workplace settings or similar groups, emerged. This second wave of HCI drew from theories such as situated action, activity theory, or distributed cognition. As computing became ever more pervasive in our everyday life, research in the third wave turned to our homes, daily routines, and culture. The embodiment of our daily activities (Dourish 2001) became an ever larger concern. As part of this third wave, there also came a turn to practice (Kuutti and Bannon 2014), which emphasises social practices as research object. Cycling spans across those three waves, as research can range from interactions with a digital device on the bike, e.g., studies that evaluate interaction modalities, mental workloads, or distraction, to studies on technology on route planning or cycling as a transportation mode choice.

Within transportation research, driver behavior – which here is comparable to a cyclist's behaviour — is often understood in hierarchical structures (e.g., Allen, Lunenfeld, and Alexander 1971; Michon 1985; Molen and Bötticher 1988). Although their approaches and nomenclature vary, all authors distinguish tasks associated with driving based on their immediacy, spanning a range from the smallest and unconscious movement of the steering wheel to stay at the center of a lane to the conscious route planning for a trip. A widely referenced structure was outlined by Michon (1985): He distinguishes tasks and associated mental processes into three levels of strategic (e.g., route choices, travel mode choice), tactical (maneuvering within traffic), and operational (steering, gear-shifting).[1]

My case studies reflect this broad scope of cycling and HCI as well. On the one hand I viewed cycling as a choice, situated in everyday routines (Chapter 4 and Chapter 5). This led to designs focused on these choices and their underlying motivations. On the other hand, I investigated cycling as an activity that is highly dependent on applying competencies in complex contexts (Chapter 4 and Chapter 6). Those include basic riding skills and the more advanced competencies needed for riding within traffic and along routes for everyday purposes. I explored an ICT system for the latter with the Virtual Cycling Coach.

With such a broad scope for information and communication technology and cycling, there is little relevant theoretical work that offers an understanding of their interplay. Research

[1] For an elaborate review on describing driver behavior see Fuller (2005).

by Marshall, Dancu, and Mueller (2016) investigated human-computer interactions while being physically in motion. They distinguish two dimensions: (1) the relation of an interaction task to the locomotion, and (2) the inhibition of interaction caused by that locomotion. While their work is an important contribution to research on human-computer-interactions while being physically in motion, it does not provide a way to structure approaches presented in this thesis. For example, artifacts that are not used in motion, i.e. on the bike, are not captured in their taxonomy. Another relevant theoretical work was done by Entwistle et al. (2015), who present the contextual wheel of practice. It is a framework for research on sustainable HCI that describes how elements present for an individual, e.g., skills, knowledge, technological artifacts, are connected to shared elements such as norms, policies, and infrastructure. It expands on the theory of social practice outlined by Shove, Pantzar, and Watson (2012) by introducing "near materiality", to situate interactive technologies within a practice. However, similarly to the analysis by Spotswood et al. (2015), this still misses the level of detail required for integrating the different roles information and communication technology can have in promoting the uptake of utilitarian cycling.

Informed by these ideas, I thus propose a conceptual framework for understanding the interplay of information and communication technology within everyday practices of utilitarian cycling. It outlines where information and communication technology can promote the uptake of utilitarian cycling.

Compositions of Practices

Social practice theory, as outlined in Chapter 2 on related work, is the foundation for this conceptual framework. In particular, I follow the view on social practice theory described by Shove, Pantzar, and Watson (2012) that the practice – rather than the one who is doing it – is at the center of analysis (Shove 2010; Reckwitz 2002). It is utilitarian cycling itself and what constitutes it, that is of interest. Technology – physical or digital – is part of the material components of this practice.

Previous work in the field of transportation described cycling – as well as other modes of transport – as *one* social practice (Spotswood et al. 2015; Watson 2012; Hasselqvist, Hesselgren, and Bogdan 2016). However, to provide a more detailed account useful for research and design of information and communication technology, this can be extended by adding another level. Much like atoms bond together to form molecules, the social practice of utilitarian cycling can be viewed as a composition of smaller practices, each themselves formed by materials, competences and meanings. Technology - digital or analog - thus becomes part of the material aspect of the small practices, as well as an agent for change of the practice itself. For example, a well designed cycling infrastructure means that little experience or skill is required to cycle, whereas cycling in a lane with mixed traffic requires more skills and is associated with more negative experiences. Another example can be found in the practice of route planning for cycling within a city. Using a paper map, one can basically try to find a short route from point A to B, while making use of previous experiences, such as knowing a bike-friendly street. Another example

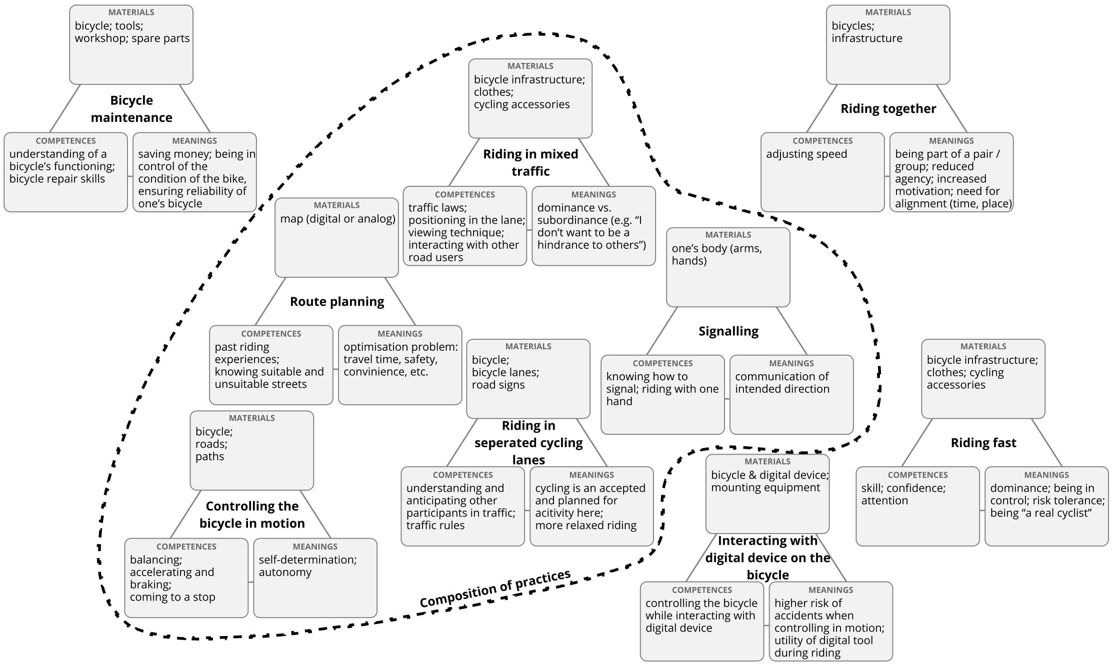


Figure 7.1: Smaller practices are combined in utilitarian cycling

are the different manoeuvring practices shown in Chapter 6. Using the Virtual Cycling Coach therein was a way of acknowledging an occurring practice, while extending it with a learning experience.

Figure 7.1 provides a visual representation of utilitarian cycling as a composition of smaller practices. When a person combines these small practices, e.g., by riding the bicycle, using a bicycle path, transporting her personal items and following a known route to a desired destination, the social practice of utilitarian cycling in enacted. Thus, any individual who chooses to cycle is then bearing a set of sub-practices in doing so.

As for HCI research and design, technology can be understood as part of the material elements used in a practice. Changes in the material elements can lead to changes of the relevant, small sub-practices. Following up on the example of route planning from above, new material elements provided by ICT, such as navigation apps on smartphones, can change existing route planning practices. The questions that emerge from that could touch on changes in meanings, e.g., what a route gets optimised for (Wagner, Winkler, and Human 2021), or changes to other small practices, e.g., how following a route on the bike is different when it was planned using the new technology.

With this framework I want to provide a conceptual understanding for how information and communication technology is – and could be – embedded in utilitarian cycling. The practices described in the subsequent sections of this chapter as well as those shown in Figure 7.1 are grounded in my own studies and related work. They are, however, not a complete list. There is room for argument about how to define and separate sub-practices, as there will be overlaps between them. Furthermore, while the focus is put on utilitarian cycling, this conceptual framework could easily be extended to cover all types of cycling by including their additional practices, e.g., around training, special bicycle equipment, or different meanings. For example, route planning for a training ride on a road bike differs from route planning for a commute home while picking up something at a specific shop. However, the initial contribution of the framework is in the description of how different practices have to be brought together – i.e. composed – for utilitarian cycling, and hence, that information and communication technology can promote the uptake of cycling through being purposefully integrated into those practices.

7.1.1 Two Dimensions Within the Human-Computer-Interaction in Utilitarian Cycling Framework

Within this conceptual framework, I propose a structure along two dimensions as shown in Figure 7.2. Along the first dimension, the practices involved in cycling can be grouped into practices that happen *off the bicycle*, such as choosing to use the bicycle, planning a trip, or maintaining a bicycle, and practices that happen *on the bicycle*, ranging from balancing, steering, to riding in mixed traffic. This first dimension offers a clear distinction for design and research on information and communication technology for cycling.

The second dimension lies within these groups: Practices differ in how simple or complex they are to perform. Dual-process theory provides a foundation to this dimension: Cognitive processes are either rapid, autonomous processes, which provide default responses, or distinctive higher-order reasoning processes (Evans and Stanovich 2013). The former represent autonomous processes that do not require working memory, typical for performances of practices any individual with the necessary competencies "can just do", or choices that are easily made. The latter processes do require working memory and represent a cognitive decoupling, that is, an abstract mental model is actively used.

As shown for example in Case Study VI on existing teaching curricula, controlling the bicycle in motion is less complex than riding in mixed traffic. Competencies are needed for most of the practices, and the dimension ranging from simple to more complex practices also reflects learning and memory systems involved in training and retrieving these competencies in-the-moment. Declarative memory is more likely involved in reflective cognitive processes of more complex practices (Evans 2008), such as planning a route or navigating *in situ* along a route while riding. Non-declarative memory systems are involved in simpler practices, where competencies are automated processes (Squire 2004).

We are typically not able to explain the *what* for balancing and steering a bike. Someone who can ride a bicycle just knows *how* to do it, without having any abstract knowledge on *what* it is that keeps the bicycle in balance. That is, we do have procedural memory – which is part of the non-declarative memory systems – that enables the skill of controlling a bicycle without a conceptual understanding of the mechanics of balancing and steering

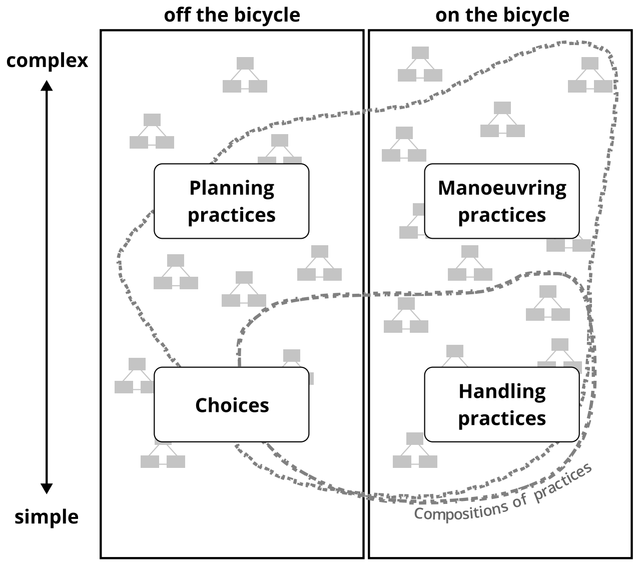


Figure 7.2: Human-Computer-Interaction in Utilitarian Cycling Framework

a bicycle. This can also be linked to the notion of embodiment, as the ability to control the bicycle is embodied in the material setting of the bicycle itself.[2]

The choice to use the bicycle can also be viewed along this dimension as a simple automated and habitual choice, or a more effortful reflexive choice (Pinder et al. 2018). The design of the interventions shown in Chapter 5 follows this view on automatic decisions, i.e. habitual transportation mode choices (e.g., Verplanken, Aarts, and Knippenberg 1997; Aarts, Verplanken, and Knippenberg 1998; Verplanken and Aarts 1999; Aarts and Dijksterhuis 2000).

The view that we stay efficient in our everyday lives by cognitively automating most activities is also present in design. Designers use signifying elements, known patterns, mappings, or affordances (D. Norman 2013) to support such automated responses, i.e. to make it simpler to perform a practice. That is how the design of most everyday things – from door handles and water faucets to automated subway doors and traffic lights – let us go through our daily lives while not spending any effortful thinking on many mundane tasks (Krug 2014; D. Norman 2013). Our non-declarative memory is well equipped to retrieve the necessary skills to perform a known practice. However, the design of road infrastructure, particularly infrastructure meant to be used by cyclists, often fails to achieve this automaticity. For example, areas such as unprotected bike lanes and conflict

[2]The question on what it is that keeps a bicycle in balance even made for an interesting discussion in the field of physics (e.g., D. E. Jones 1970; Kirshner 1980; Meijaard et al. 2007). To anyone interested in the topic, I highly recommend reading the insightful and entertaining article by D. E. Jones (1970): *The stability of the bicycle (1970, Physics today 23, 4, p34–40).*

zones where bicycles and vehicles mix generate a high mental workload due to the sudden complexity of a particular situation (Ryerson et al. 2021).

Automaticity is also arguably different between individuals depending on their level of cycling experience. As shown in the case studies, experienced cyclists negotiate within complex urban traffic scenarios with more ease than novice cyclists. The latter can struggle to perform practices, indicating a stronger involvement of slow, reflective mental processing, which is trying to understand, control, and decide in-the-moment. This was most pronounced in Case Study III, the Bike Buddy Program, where the pair often disagreed on what was a feasible way of incorporating cycling for regular commuting. Thus, some practices may be simple to perform for an experienced cyclist, but be outside of a beginner cyclist's composition of practices, as shown by the different compositions of practices in Figure 7.2. Which information and communication technology for promoting the uptake of utilitarian cycling is useful for a person thus depends on the practices she or he composes. For example, a technology like the Virtual Cycling Coach is only relevant for someone proficient in simple handling practices, or interventions such as Radelt zur Arbeit or the Biking Tourney (Chapter 5) for promoting bicycle commuting are only suitable for persons who can perform the required practices for doing so.

7.1.2 Four Fields of Practices

Practices for utilitarian cycling can be structured along these two dimensions into four fields where information and communication technology can be integrated (Figure 7.2):

- **Planning Practices**: These encapsulate practices that happen while not riding. Those include planning a route, or preparing to ride, e.g., combining knowledge on the weather with the selection of clothes and picking a suitable bag for carrying one's personal items. Further examples of such practices are route planning, deciding for known routes, setting up rides with other persons, planning to rent a shared bicycle, or maintaining one's bicycle.
- **Choices**: This field covers how individuals embed utilitarian cycling in their everyday life by deciding to form a composition of practices, such as the choice to use a bicycle as a mode of transportation as opposed to alternatives. Motives, goals, habits, and situations are of concern here. Choices and actions can range from highly automated – e.g., doing every commute by bicycle – to highly effortful such as deciding to ride to an unknown area. Other examples for such effortful activities are estimating and assessing travel times, or assessing travel alternatives.
- **Manoeuvring Practices**: This field of practices covers the interactions on-the-bicycle within a context and with other traffic participants. This includes riding on a built street, following traffic rules, interacting with pedestrians, cars, and other cyclists. Further examples are indicating line changes, following a route, or finding bicycle storage facilities. These practices are situated in-the-moment and involve

the combination of the present material elements, such as the built infrastructure, with meanings, such as traffic laws, and competences.

- **Handling Practices**: These are concerned with more fundamental doings necessary for cycling. These practices are the first to be learned when someone begins cycling. They happen on the bike, and often last for just seconds. Examples are starting to ride, keeping balance, braking, putting down legs after a stop, accelerating and decelerating, or steering, which can be summed up as *being in control of the bicycle*. The necessary competencies are typically formed through experiential learning.

Examples for such practices off the bicycle are visualized in Figure 7.3. Examples for practices on the the bicycle are visualized in Figure 7.4.

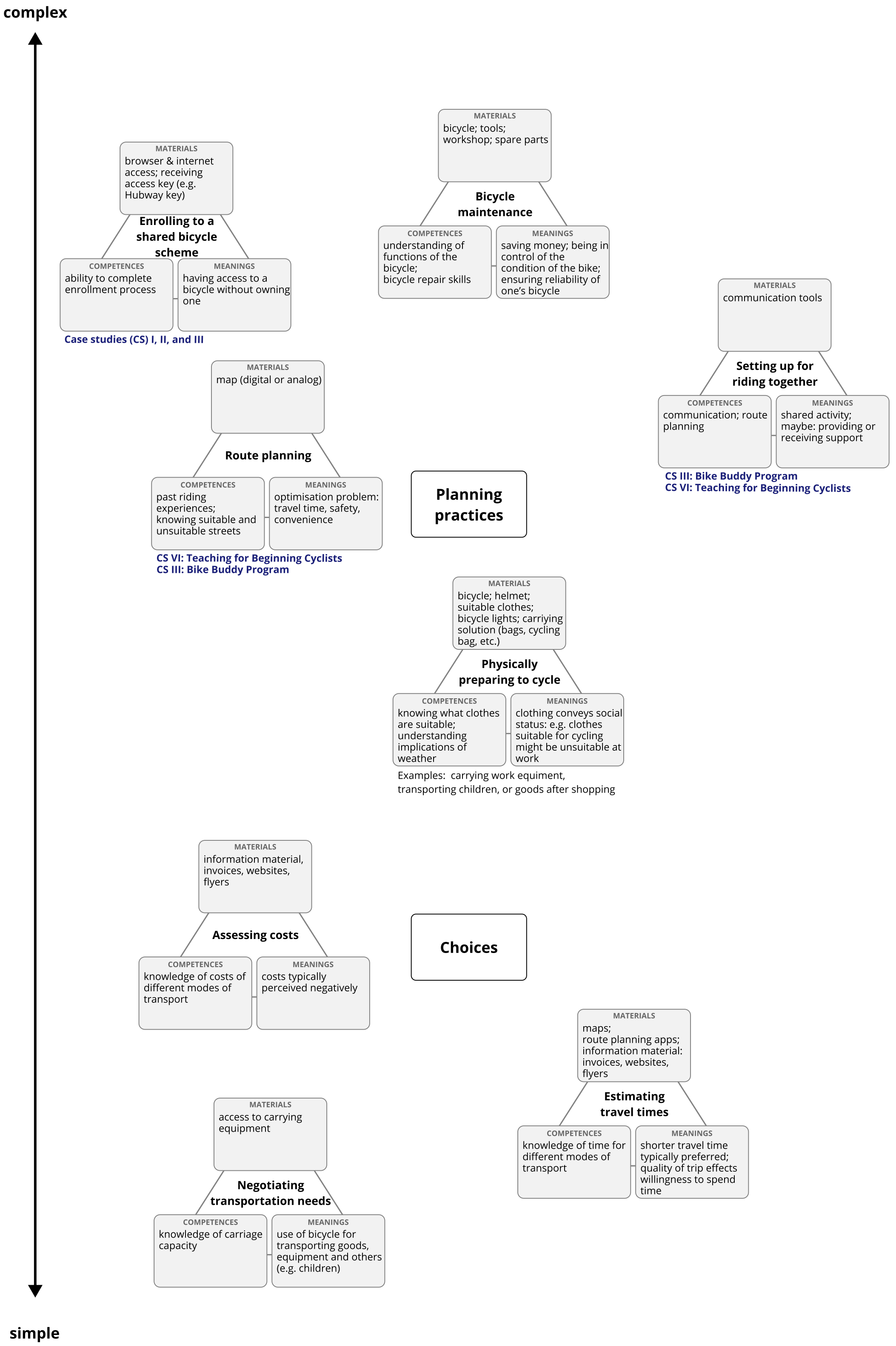


Figure 7.3: Off-the-bicycle practices (examples)

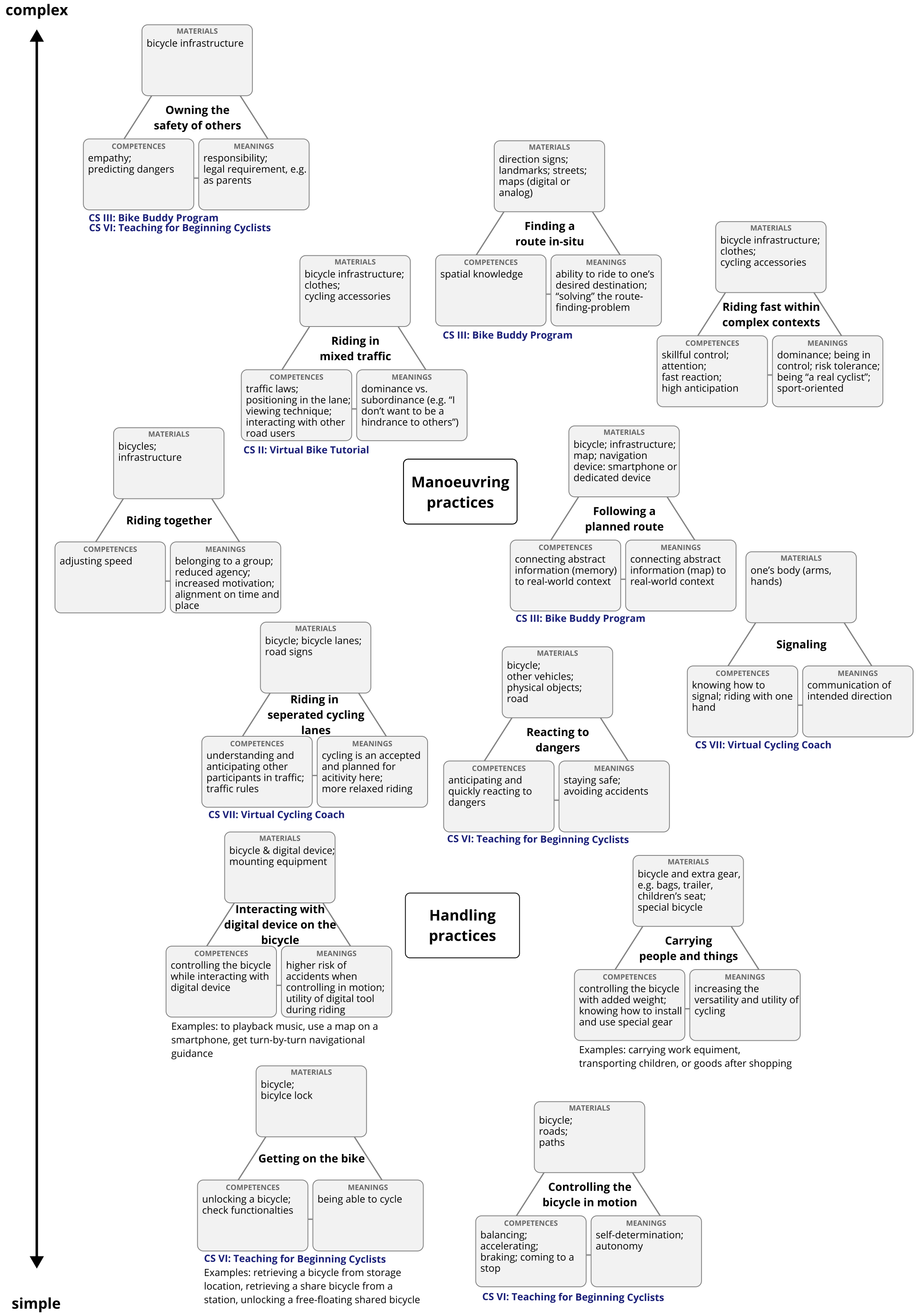


Figure 7.4: On-the-bicycle practices (examples)

7.2 HCI Research and Design Within the Conceptual Framework

Planning Practices

Across my case studies, I found multiple planning practices. Within the first three case studies, enrolling and using a shared bicycle scheme was an important practice for the participants that did not own a bicycle. Bicycle maintenance also came up, particularly around the need to repair one's own bicycle in order to use it. In Case Study III (Bike Buddy Program), the support between cyclists was investigated. This also revealed difficulties with several planning practices: Scheduling a ride together, planning a route which is suitable for the pair, or planning in enough time especially when using a shared bicycle. The practice of route planning was also highlighted by the cycling coach in Case Study VI (Teaching and Coaching for Beginning Cyclists). For example, he invested significant effort into planning a route suitable for the commutes his students had to do, and using this route as part of the coaching was seen as an important method for enabling students to use the bicycle for commuting. Table 7.1 shows related work that covers the integration of ICT into planning practices.

Table 7.1: HCI research on planning practices

Reference	Summary
Hasselqvist, Hesselgren, and Bogdan (2016)	Opportunities for ICT applications for supporting a car free lifestyle including (1) supporting odd types of vehicles, (2) providing services for transporting stuff, (3) facilitating helping and (4) travel planning tools that optimise beyond travel time
Götzenbrucker and Köhl (2012)	Route planning app that provides alternative transportation modes and multi-modal transport options to promote active mobility.

Choosing Utilitarian Cycling

Case studies I (Frequent Cycling Challenge), IV (Bike to work) and V (Biking Tourney) investigated the interplay between information and communication technology and the choice to use the bicycle for utilitarian transportation. They are hence clearly situated within the field of "Choosing Utilitarian Cycling". The designs of the used technology probes were grounded in insights from decades of research in (social) psychology. Those include the influence from being part of a group or team, social comparison enabled by technology, or competition with others. Participating in such a campaign can act as a commitment (Cialdini 2007), which in turn affects transportation mode choices. Such interventions also convey social norms, e.g., colleagues also cycle on days with bad weather. If those are effectively communicated and accepted – which remains a question in itself – those could play a role in future choices. Both commitment and social norms

Table 7.2: HCI Research on Choosing Utilitarian Cycling

Reference	**Summary**
Raman Kazhamiakin et al. (2021)	Gamification platform to develop and run sustainable mobility campaigns promoting individual green mobility behaviors.
R. Kazhamiakin et al. (2015)	Using gamification to promote sustainable urban mobility
Wernbacher et al. (2015)	Pervasive gaming approach with location-based elements for promoting environmentally sustainable mobility choices
Gabrielli, Forbes, et al. (2014)	Providing feedback on CO_2 emissions and presenting challenges to increase choices of environmentally friendly transportation modes.
Flüchter, Wortmann, and Fleisch (2014)	Providing social normative feedback to promote e-bike commuting
Laschke et al. (2014)	Design of a key holder that creates friction when choosing the car key instead of the bicycle lock's key to increase physical activity. Quickly grabbing the car key creates friction, but with deliberate care the system can be circumvented.
Jylhä et al. (2013)	Application that tracks trips including CO_2 emissions to present a set of actionable mobility challenges to the user
Broll et al. (2012)	App providing feedback on cost, environmental impact, health and virtual coins
Froehlich, Dillahunt, et al. (2009)	App to sense and reveal information about transportation behavior

can ultimately affect choices (Evans and Stanovich 2013). Similarly, the team dynamic described in Chapter 5 may lead to changes in the choice to use the bicycle.

The interventions from the case studies also incorporated feedback in various forms. Such real-time feedback to affect conscious decision-making is present in many studies on sustainable HCI (Brynjarsdottir et al. 2012). However, the implicit assumption that there is a causal relationship between available information and choices has been critiqued substantially, both for its lack of nuance and implicit assumption of humans as rational agents (Sniehotta, Presseau, and Araújo-Soares 2014; Ariely 2010; Brynjarsdottir et al. 2012).

Related work shown in Table 7.2 follows very similar themes of:

- presenting social normative feedback

- presenting ecological feedback (e.g., one's CO_2 emissions)
- introducing game-like elements such as collaboration, challenges, or competitions

Like the case studies within this thesis, most studied interventions on choices target a reflective participant that acts on presented information. A notable exception from these overall themes is the work by Hasselqvist, Hesselgren, and Bogdan (2016), which provides insights into the real-life car-free lifestyle and the opportunities for ICT applications. Another is the design of "Keymoment" by Laschke et al. (2014), which is a key holder for car and bicycle keys designed to support implementation intentions of using the bicycle more often. If one grabs the car key – likely a habitual and thus automated action –, the bicycle key drops to the floor. If it is then picked up, one is reminded about the intention to use the bicycle more often. Designs and studies on those more subtle interventions in important moments are rare and show a gap to be tackled by future research.

Manoeuvring Practices

Moving to the manoeuvring practices represents at the same time a move to the on-the-bike experiences. Information and communication technology is here expanding existing small practices. Case study VI (Teaching and Coaching for Beginning Cyclists) showed the importance of the manoeuvring and handling practices. For someone learning to ride a bike, daily transportation choices simply do not include the bicycle as an option yet. There, bicycle control skills need to be obtained through training. More advanced riders then learn the skills to ride within more complex contexts and interact with traffic. Furthermore, they obtain and apply knowledge of traffic rules needed for this. Overall this case study supports the distinction into the different fields of practices and also highlights that for beginning cyclists they are of hierarchical nature, i.e., one needs to be able to ride and control a bicycle (handling practices) within a real environment with traffic (manoeuvring practices) to choose cycling.

As for manoeuvring practices, my findings regarding the role of skill were first put into the design of a technology probe of Case Study II (Virtual Bike Tutorial). The training content was focused on the skills for urban cycling. The intervention used a virtual training on a personal computer. Hence, it was detached from the elements that form the practice and make it a real cycling experience. This led to detached learning, an accumulation of knowledge retrievable from declarative memory. However, no connection of these competencies to the actual practices on the bike, nor to perceived self-efficacy, were established. It can be argued that there was simply too much of a disconnect between the competencies gained through this intervention and the manoeuvring practices on the bicycle.

Case Study III (Bike Buddy Program), removed technology from the equation and focused on support provided by experienced cyclists. When reflecting upon them, the sessions were seen positive by the participants. They particularly benefited from the explicit training of cycling competencies for manoeuvring practices, e.g., positioning one's bike,

Table 7.3: HCI research on manoeuvring practices

Reference	Summary
Rittenbruch et al. (2020)	The authors create a prototyping toolkit to allow participants to safely explore interaction designs for on bicycle notifications. Notifications itself could be hazard warnings.
Andres et al. (2019)	Co-operating with an eBike to ride with efficient speeds
Matviienko, Ananthanarayan, El Ali, et al. (2019)	Navigational cues
Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. (2018)	Visual, auditory and vibrotactile warnings for children
Waard et al. (2017)	Comparison of auditory and visual turn-by-turn route guidance on the bike
Cheng and Lee (2015)	A mobile app allowing users to connect over the internet to create a sense of cycling together.
Dancu, Vechev, et al. (2015)	Projection surfaces and turn signal systems
Dancu, Franjcic, and Fjeld (2014)	Map navigation using a bike-mounted projector
Sörös, Daiber, and Weller (2013)	Continuous status display, ambient notification, hands-free interaction and communication between teammates using Google Glass
Steltenpohl and Bouwer (2013)	Tactile navigation support for cyclists
Reddy et al. (2010)	Enriching the experimentation of route discovery and sharing routes using a mobile phone application and online map visualisation
Poppinga, Pielot, and Boll (2009)	Using tactile display for supporting navigation of tourists on a bicycle trip
Rowland et al. (2009)	Adding to the cycling experience with a guided heritage tour
Rowland et al. (2009)	Adding to the cycling experience by recording and listening to personal stories
Tsukada and Yasumura (2004)	Multiple directional information with the tactile belt

doing left turns or avoiding opening car doors. There were however also substantial drawbacks to this setting: Scheduling was difficult to do and the bike buddy mentors were at times not viewed as peers because they were "real bikers". This shows that the meanings of different practices are not universally shared. As shown in this case study, reported experiences and judgements of the same situations could differ strongly between the novice and experienced cyclists.

In Case Study VII (Virtual Cycling Coach), the coach was virtual while the experience on cycling was real. When viewed within this conceptual framework, a key aspect of this intervention was that it involved the composition of the actual practices for cycling, particularly controlling the bike and maneuvering within a real traffic scenario. The content of the VCC curriculum covered competences for handling and manoeuvring practices. The former included exercises such as accelerating and coming to a standstill or riding in a straight line while looking back over one's shoulder. The latter, which also formed the majority within the evaluation studies, involved exercises like riding in areas with traffic and interacting with vehicles and pedestrians. While training competencies for a set of different practices, using the Virtual Cycling Coach can itself be seen as a practice that got added to the composition of cycling by the study participants.

Related work on manoeuvring practices is shown in Table 7.3. A common theme within published research for in-the-moment support within HCI research is information and communication technology for navigational guidance. Waard et al. (2017) compared a map displayed on a smartphone, auditory route guidance, and a dedicated system with flashing lights for supporting navigation. Modes of interactions such as tactile feedback for navigation support have also been studied in detail by Poppinga, Pielot, and Boll (2009), Steltenpohl and Bouwer (2013), and Tsukada and Yasumura (2004). On-bicycle navigation has also been studied to support excursions and the exploration of unfamiliar environments by bicycle (Pielot et al. 2012; Poppinga, Pielot, and Boll 2009).

Interventions on the interactions between cyclists and their context have also been explored, such as using projections from the bicycle as a means to communicate with other traffic participants Dancu, Franjcic, and Fjeld (2014) and Dancu, Vechev, et al. (2015). Context-aware sensing has been used to help cyclists regulate their speed to cross all traffic lights on green, taking into account the cyclist's context and actions. This "[...]'sensing and acting' on information to assist the rider, not only 'cognitively' but also 'physically', to facilitate user-system co-operation in an exertion context" (Andres et al. 2019).

Handling Practices

Handling practices are the fundamental practices for cycling. In Case Study VI (Teaching and Coaching for Beginning Cyclists, the novice cyclists were primarily concerned with learning the competences needed to control the bicycle in motion. This can be broken up into even smaller practices such as balancing, steering, braking, gear-shifting, etc.

A recently started study by Michahelles and Wintersberger (2021) wants to evaluate a self-balancing bicycle, thereby altering the practice of balancing by integrating a new technology (i.e. a self-balancing bicycle). As shown in Table 7.4, interacting with information and communication technology on the bike can also mostly be situated within handling practices. A large theme within HCI research thereby is the evaluation of different interaction modalities to study their effectiveness. Examples include auditory, haptic, and visual cues for the cyclist.

The studies shown in Table 7.4 also highlight that there is no clear cut distinction to manoeuvring practices. For example, Pakkanen et al. (2008) studied the use of vibro-haptic feedback for interacting with the cyclists in general, whereas Matviienko, Ananthanarayan, El Ali, et al. (2019) then use vibro-haptic feedback to support following a route. This shows how technology can become part of different practices.

Table 7.4: HCI research on handling practices

Reference	**Summary**
Michahelles and Wintersberger (2021)	concept of a (partly) automated bike with active safety functions that can be fully integrated into automated transport systems
Marshall, Dancu, and Mueller (2016)	Interacting with a computing device while being physically active and in motion
Stelling-Konczak, Hagenzieker, and Wee (2015)	Use of electronic devices while cycling and likelihood of accidents
Okugawa et al. (2015)	Training system of bicycle pedaling using auditory feedback
Bial et al. (2012)	Tactile feedback with actuators integrated in cyclists' shoes.
Pakkanen et al. (2008)	Specification and perception of vibro-haptic stimuli when biking

7.3 Chapter Summary

This chapter introduced a conceptual framework for HCI design for utilitarian cycling. It draws on existing empirical and theoretical work and critically reflects on the empirical work done for this thesis. It helps to unpack the social practice of utilitarian cycling by understanding it as a composition of smaller practices. Those can be structured into the ones on the bicycle, manoeuvring practices and handling practices, and ones off the bicycle, the planning practices and choices. Furthermore, I presented an overview on how previous research maps to the framework to conceptually structure different HCI interventions. This framework offers a theoretical foundation to situate ICT for promoting the uptake of cycling in. New technology is thereby seen as either an addition to existing practices, or enabling new practices to emerge and possibly get integrated into a composition.

CHAPTER 8

Discussion

This thesis set out to explore how information and communication technology can promote the uptake of utilitarian cycling. The case studies presented in the earlier chapters offer insights into both the choices to use the bicycle and the practices involved in everyday cycling. Eventually, this informed a conceptual framework that structures the role of information and communication technology in the realm of utilitarian cycling.

8.1 Answering the Research Questions

The three main research questions that guided this work were:

- *RQ1: How does the introduction of information and communication technology to promote cycling affect the uptake of utilitarian cycling?*
- *RQ2: How can information and communication technology provide motivational support for the choice to cycle?*

[1]During my work for this thesis, I had an epiphany once. My collaborators and I were preparing a prototype of the Virtual Cycling Coach to be tested in the study presented in Chapter 6. To test the technical setup, I had prepared the prototype in a small messenger bag with equipment. I rigged up a bicycle with action cams used to record the upcoming sessions with study participants. One of my research partners, with whom I have spent more than one year discussing, creating, and evaluating technology in the realms of urban transportation, got on the bike to try out the setup. At that moment, her mood changed. Our perspective changed. Using a bike was not anymore a choice, something people do or do not do, or a statistic. It was an immediate, personal and visceral experience for my colleague. There were layers on layers of complexity around us: The built environment, the streets, pavement, pedestrians – some watching, some not even looking –, the bicycle with its very own characteristics of being handled, and our prototype to top it all up. Everything contributed to how my colleague experienced this moment, and this experience was distinctly different from abstract concepts. The conceptual framework presented in Chapter 7 is also an attempt to capture the many elements that go into a social practice like cycling.

- *RQ3: How can information and communication technology facilitate in-the-moment support for cyclists?*

When we think about a practice such as cycling, our mind immediately serves us with an understanding of this familiar activity. Due to this familiarity, there is no obvious need to build an understanding of the activity of cycling, as we already have "our theory" for making sense of cycling at hand. However, by looking across the presented case studies and reflecting on the problem space of information and communication technology for cycling, the seemingly simple activity of cycling reveals a surprising amount of complexity.[1]

Essential to answering RQ1 is the insight that there is a distinct difference between information and communication technology that is used off-the-bicycle, e.g., an app that provides daily recommendations, and technology used while cycling. On the one hand there are interventions such as the Biking Tourney, that present data like saved emissions, leaderboards, or distance travelled. This represents mental models – in this case, the competition between companies – that are mostly detached from the experience of cycling. On the other hand there are designs such as the Virtual Cycling Coach, which is very much situated in-the-moment of riding. This is reflected in the conceptual framework by the distinction into practices *off-* and *on-the-bicycle*. By showing the spectrum of practices from simple to complex practices, the framework also offers a nuanced view on cycling. Information and communication technology can be embedded in existing practices, or enable new practices for cycling. In doing so, it can support the adoption of utilitarian cycling. This was instantiated both through the case studies and by situating related work within the framework.

The Human-Computer-Interaction in Utilitarian Cycling Framework also blends in all facets of the three waves of HCI as a discipline (Harrison, Tatar, and Sengers 2007; Bødker 2015): It is concerned with human factors, with an emphasis on cognitive processes, information processing, and basic human-computer-interactions. This is covered along the dimension of simple to complex practices, that encompass the difference between split-second automated actions to more reflective decisions. By understanding cycling as a composition of practices, the role of different competencies – along with meanings and materials – becomes more apparent. When I started my research on the transportation mode choice for cycling, I abstracted competencies by assumptions such as "being able to ride a bicycle". Over the course of the studies, I gained insights into the vast set of competencies needed to use a bicycle for daily transportation needs. This informed the design of the Virtual Cycling Coach (chapter 6). Furthermore, I emphasise the importance of real-life contexts across the case studies, thus placing my approach strongly within the third-wave of HCI. I studied human experience due to interactions with computers in everyday life. Bødker (2015) argued before that, as technology spreads to our everyday lives and culture, research and design should embrace the creation of meaning through technology. I did this, e.g., by investigating game-like elements for motivation (chapter 5) or by using technology to change a bike ride to a learning experience (chapter 6).

Moving on to RQ2, Chapter 5 provided answers on how to offer motivational support through technology. We[2] found that apps and web platforms can help their users get or stay motivated to cycle more regularly. These technologies, however, do need to be sufficiently embedded in social settings, such as workplaces. Furthermore, it was highlighted how choices are motivated by aspects beyond time or costs. The choice to cycle is also informed by associated meanings such as a gain in health, doing something for environmental protection, and being part of a team.

Over the course of the case studies, it also became clear that starting to use the bicycle and adopting it as a means of transport can often be challenging. The need to execute control over the bicycle while navigating and interacting in traffic is inherently non-trivial. Adopting cycling for transportation often involves negative experiences, such as fearful moments in traffic, feeling vulnerable, or being negatively overwhelmed. Here again, the framework introduced in the previous chapter offers a coherent theoretical understanding of the hierarchical relationship of those different aspects of cycling.

Moving to RQ3, the role of cycling competencies, i.e., the skills, knowledge, and coping strategies critical for safe and comfortable utilitarian cycling, was explored in more detail. Previous research already showed that children need to develop those competencies to uptake cycling (Ducheyne, De Bourdeaudhuij, Lenoir, Spittaels, et al. 2013; Ducheyne, De Bourdeaudhuij, Lenoir, and Cardon 2013). Case Study VI (Teaching and Coaching for Beginning Cyclists) points to the same being relevant for adults. In Case Study VII (Virtual Cycling Coach), we then probed into information and communication technology that provides in-the-moment support. The explored coaching intervention showed how technology can help build those competencies, with a system taking an active role in supporting learning grounded in real experiences. It thereby introduced a new practice of learning in-the-moment that can be added to a person's composition of practices for cycling. Other designs may rather alter elements of existing practices, e.g., by extending the functionality of a route guidance app.

The scope of studies on HCI and cycling introduced earlier in this thesis is broad as it covers – among others – studies on different modes of interaction, providing navigational guidance, context-aware sensing, giving warnings, giving feedback on transportation-related greenhouse gas emissions, or incorporating game-like elements (see Chapter 2 and Chapter 7). As computing might eventually become pervasive in everyday cycling, it may play a bigger role for handling practices. Concepts of self-balancing bicycles (Michahelles and Wintersberger 2021; Sharma et al. 2016) are an example of how computing could change both the experience of the physical properties of the bicycle as well as the interaction humans have with their bicycle. Integrated warnings, as studied by Rittenbruch et al. (2020) and Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. (2018), could become a way to prevent accidents and increase safety, particularly for children or beginning adult cyclists. As for planning practices, routing algorithms already try to incorporate the complexity posed by different cycling infrastructures (Murphy

[2] "We" as this research has been done together with colleagues as disclosed in the chapters above.

and Owen 2019). Supporting the uptake of utilitarian cycling through information and communication technology can thus be tackled in a plenty of ways which are captured in the Human-Computer-Interaction in Utilitarian Cycling Framework.

8.2 Discussion of the Human-Computer-Interaction in Utilitarian Cycling Framework

The conceptual framework presented in this thesis emerged over the years I have been working on this research topic. It draws from multiple theoretical ideas, literature on the topic, interviews and reflections about utilitarian cycling, my own experience doing this research and cycling myself. It hence follows a hermeneutical approach to understanding the problem space of HCI and cycling. However, its purpose is not to serve as a theoretical foundation for designing a system in the first place. This contrast between theory-based design and hermeneutics has been highlighted by Carroll and Kellogg (1989). It rather is a "wild theory" (Rogers 2012), insofar as the practice of cycling is of individual and societal concern, and thus the starting point, whereas the role of information and communication technology is then "[...] to augment, facilitate or change it in ways that individuals and society desire. The problem-design space is couched in terms of an embodied, ecological, or other new theoretical understanding of how people behave in their everyday world and how an in-the-wild design could change this" (ibid.).

This conceptual framework could be relevant for future HCI research for cycling in at least three ways: First, it unpacks the complexity behind the seemingly mundane activity of cycling in a structured way. The four quadrants of choices, planning practices, manoeuvring practices, and handling practices, map out areas for HCI interventions and thus also help to identify streams of related research. Second, the concept of sub-practices can help researchers to situate their research beyond those quadrants. Single sub-practices and the potential role of digital technology for them can be explored. Third, the framework moves beyond the individual and highlights the importance of material elements and shared meanings. This can be used to sensitise researchers to investigate aspects beyond observable actions by individuals, e.g. such as Heesch et al. (2017) investigated how manoeuvring practices from motorists, such as passing in close distance, create experiences of harassment for cyclists.

8.2.1 Overlapping Theories

As software and hardware we use daily has gotten ever more pervasive over the past decades, many theories may apply to analyse this topic. One can be found in a view of action being embodied (Dourish 2001), which got more prominent in HCI research. A central argument here is that the regular use of such systems does away with the need for conscious awareness for doing so. Human action and interactions become intersubjective and bodily activities. Thereby, meaning exists in *the doing* rather than derive from a rational process. Similarly to the used concepts of social practice theory, the work of Dourish (2001) is also grounded in earlier texts from the late Wittgenstein (1968) and

Heidegger (1962). Reckwitz (2002) and Shove (2010) argue for social practices as a concept for understanding action within society.

Another theoretical view could focus solely on cognitive aspects. The idea of automated cognitive processing has to be understood as interconnected with the world around us. This idea of cognition *in the head* and *in the world* has been popularised by Norman (D. A. Norman 1993). More recent research in cognitive science supports the notion that "cognition is fundamentally action-bound, subserving the planning, selection, anticipation, and performance of actions. Thus, cognition and action are not only closely interrelated – cognition seems fundamentally grounded in action" (Engel et al. 2013). Automated processing seems to be the mechanism that connects the world without mental representations of it. Putting ontological and epistemological differences aside, "automaticity" or "type 1" processing in the cognitive sciences seem to capture the same phenomena of our everyday lives as "embodiment" and social practice theory try to do.

There are also parallels in this framework to Activity Theory. It has a similar hierarchical structure moving from "activities" to "actions" and "operations" (Kuutti 1996). Activity theory has "[. . .] much to offer to HCI, in terms of providing a means of analyzing actions and interactions with artifacts within a historical and cultural context" (Rogers 2012). With that, many of the concepts introduced above might be equally viewed using an activity theory lens. However, in leaning on concepts that are well established in understanding driver behavior in transportation research, the presented framework should help bridge gaps between research disciplines.

8.2.2 Other Types of Cycling

While the focus in the presented case studies has been on utilitarian cycling, the framework itself can be well extended to other types of cycling, such as mountain biking or road cycling. Within them, there are similar practices consisting of the material things one needs to perform them, the competences necessary to do so, and the meanings of it. However, those may differ between the types of cycling. Information and communication technology can then get integrated within such existing practices or enable entirely new ones to emerge.

8.2.3 Limitations of the Framework

As HCI design and research move beyond the lab, they become more complex to conduct and interpret (Rogers et al. 2007). This conceptual framework is therefore a wild theory (Rogers 2012): Rather than a theory in the post-positivistic sense that makes predictable claims that can be verified with measurements, it presents a set of constructs to understand and guide research and design. Those constructs are used as sensitising concepts to how we conceptualise the interplay between cycling and ICT within everyday activities.

One of those concepts, the distinction between simple and complex practices, presents a challenge for applying this framework. Correctly attributing complexity to practices is a non-trivial task. This has been done in transportation research, e.g., with studies using sub-tasks to measure reaction times to assess mental workloads. Thus far, the same methods have rarely been translated to research on cycling.

8.3 Cycling Infrastructure, Competencies, and Policy

The findings presented in this thesis have to be seen in a wider context of transportation practices. While interactive technologies can play some role in staying physically active by choosing the bicycle or by supporting cyclists on the bike, there are also larger effects in play. There is a known relationship between the share of cycling within any given region and the build infrastructure (Pucher and Buehler 2008; Heinen, Wee, and Maat 2010). Infrastructure also plays the dominant role in shaping an individual's experience, and the experiential quality of cycling has been shown to affect the choice to use a bicycle by Crist et al. (2018) and Stinson and Bhat (2005). The role of cycling infrastructure – or lack thereof – also was a topic in almost every interview and informal chat I had about utilitarian cycling. There is, however, still little research on the relationship between infrastructure and cyclists' experience, with the recent exception of Ryerson et al. (2021) who used biometric readings to measure stress introduced within the built infrastructure.

8.3.1 Cycling Infrastructure and Experiences of Cyclists

My studies show that the physical context is strongly connected with the experience of cyclists. As described in Chapter 6, beginning cyclists are riding in traffic-free areas and the transition to riding in regular street context – especially within dense urban traffic – induces challenging experiences. When designing ICT, one has to acknowledge that it is always embedded into such experiences. These same experiences can also be understood as key to designing supportive technology.

There are also similarities between interacting with built infrastructure and software: From the point of view of their users, they just are as they are – that is – the creative process that brought their form and function into existence is hidden and is something that typically does not cross one's mind. But actually, they are all designed (D. Norman 2013). Infrastructure enables or prohibits interactions. It uses signifiers such as lane markings or road signs, affordances such as raised lanes or sidewalks, blockades, ramps, etc. And, it is built in a way that reduces the mental workload of its users, similar to what is typically a major goal in user experience design for software development (Krug 2014). From an experiential perspective, the built infrastructure has hence more in common with most interactions with computers we use daily than the interventions I studied in this thesis. Whereas the former is *just there*, the latter was built to make one think and reflect.

Finally, cycling, especially utilitarian cycling in urban contexts, is a complex activity in complex settings. It is probably more visceral, bodily, and emotional than walking or driving. This might explain why it is – at the same time – the most enjoyed and most feared mode of transportation. Assuming that remembered experiences are affecting our future choices (Kahneman 2011), only by having a "good enough" experience doing something, an activity will get integrated into our everyday life. Existing research shows that policy, and especially a policy of building well-designed cycling facilities, is the most important factor for enabling those positive experiences (W. Chen et al. 2022; Pucher and Buehler 2008). Beyond that, digital technology can play a role as well. E.g. routing services that can help to find and cycle along a satisfactory route, or smartwatches that can track one's physical activity, thus highlighting the health benefits of utilitarian cycling. The Virtual Cycling Coach presents another avenue to affect the experience in a positive way by supporting competence development. All of those systems can affect experiences of cycling and thus, eventually, the choice to cycle.

Given the interdependence between cycling infrastructure, policy and digital technology, its users should have a role in shaping those. As for the design of ICT for cycling, the later case studies in this thesis were informed by insights from my earlier studies. However, the influence on the design of such technology by its users could be much stronger. Currently, there is little published work that used methods such as Participatory Design to envision and create digital technology that would support people to adopt utilitarian cycling. Future HCI research could tap into that gap, thus also further exploring cyclist's needs and thus requirements for ICT.

8.3.2 Competence Development

Overall, there is still remarkably little research on the connection between the built infrastructure and the role of competencies for cycling. Case Study VI (Teaching and Coaching for Beginning Cyclists) and Case Study VII (Virtual Cycling Coach) showed that competencies are important for cycling and that there are opportunities to support competence development through technology. These studies also highlighted the particular competencies a cyclist needs to safely and conveniently travel by bike. They furthermore showed that situated, in-the-moment support can help novice cyclists and also convey best practices to more experienced cyclists.

Across the case studies, there is a seemingly contradiction in the role experienced cyclists can have to support and motivate novices. In Case Study III (Bike Buddy Program, I highlighted that there is a spectrum ranging from "being supported" to "not want to be like them". In Case Study IV (Radelt zur Arbeit), my results highlight on the positive relationship between the two groups. This could be a result of (a) only people willing to be part of a team with other cyclists participating in the first place, (b) the different methods used, as the evaluation of Radelt zur Arbeit was done using standardised surveys which are less open to unexpected findings.

Cultural differences between Austria (case studies IV, VI and VII) and the U.S.A. (case studies I, II, III, V, and VII) may also play a role in that regard. The more widespread cycling is within a culture, it is also seen as more normal, as safer and generally viewed with less concern (Aldred and Jungnickel 2014). This may explain a starker contrast between novice and regular cyclists in areas where utilitarian cycling has a lower prevalence.

This has implications for game-like elements as probed across the case studies: Novice cyclists may view systems that include social challenges as detracting, if these features are seen as “being there for the real cyclists“, thus not for me. A further implication for the design of ICT is that even with a focus on utilitarian cycling, users of a similar system may have vastly different self-images and experiences doing so, depending on their cycling proficiency. Finally, information and communication technology, such as the Virtual Cycling Coach, can be a neutral form of support, i.e. the person on the bicycle is empowered to decide to use, ignore, or abandon such a system.

8.3.3 Policy and Activism

Policy, particularly the built cycling infrastructure that depends on it, is probably the largest factor in contributing to transportation mode choices. A theme throughout research on cycling in general and the research presented in this thesis is that the adoption of cycling in one’s everyday routines is directly related to the available infrastructure, that is, safe cycling lanes and well-designed streets that enable convenient and safe travel by bicycle. Information and communication technology should and cannot counteract the effects of policy decisions. But using technology to support political activism might be an angle to this.

ICT designs could be used to connect citizens with policy for a community-level action on local legislation. For example, recent advancements in virtual and augmented reality applications could be used to involve citizens in urban planning practices. They could provide the opportunity to make citizens experience changes in their environment that enable environmentally sustainable practices, e.g., by creating neighbourhoods with reduced motorised traffic and open green spaces for a heat-resilient, resource-efficient neighbourhood. Another example of interventions on the policy level would be technology that connects outcomes of elections with its impact on sustainability (Brynjarsdottir et al. 2012). Finally, the use of an activist lens on sustainability in the design change interventions for individuals and the collective has also been previously proposed by Ganglbauer, Fitzpatrick, and Comber (2013). As shown in the case studies, supporting people to uptake cycling can be in the interest of regular cyclists as a means to generate political pressure for building good cycling infrastructure. Building on those motives, technology could have a facilitating role in pushing bike-friendly policy decisions.

8.4 Reflection on Sustainable HCI

I also want to critically reflect on the motivation for technology design in the realm of utilitarian cycling. Given an ever-rising awareness of climate change’s severe consequences for humanity, HCI researchers and designers want to contribute to a more environmentally sustainable world. Hence, sustainable HCI has been a trend within the previous years on a path to “move beyond simple models to grapple with the full multi-scalar complexity of 'wicked' sustainability problems" (Silberman et al. 2014). While this is a worthwhile motivation for doing research or developing new products, I find it also important to show the limits of technology as studied for this thesis and in the field of transportation.

8.4.1 Beyond the Individual

The social practice theory approach used to inform the framework in Chapter 7 aims to move beyond individual persons and their interactions, choices, or statements. Technologies that put the individual at the centre to promote environmentally sustainable actions are often designed for a rational, technically minded, cost and environmentally aware and potentially male person – „resource man" (Strengers 2014). But this does not reflect the reality of everyday life. In a more nuanced understanding, resource consumption can be seen as embedded in the fuzzy everyday and arising from an interplay of practices. For example, people rarely think about the energy-consuming activities in the household in terms of the energy they consume, but rather as the „purpose" they fulfil (Brynjarsdottir et al. 2012). Similarly, getting from A to B on a bicycle is not about the light physical activity to strengthen one's health or CO_2 emissions, but about sharing an understanding of cycling that is part of the practice of using a bicycle, as are the material elements of the bike and the competencies to do so.

This view emphasises the "doings", understanding them as routinised practices widely shared throughout society, contextualised by being bound to time and space, and strongly interconnected with other practices. A practice approach – quite similar to action- or activity-based descriptions – demands attention to how practices bundle together in people's lives. This orients our thinking to a more systemic level by pointing out how particular practices are embedded within each other, e.g., residential living and working practices are often intertwined with transportation practices, forming a system of practices (Watson 2012). A shift away from the rational sovereign consumer has already occurred in consumption research (Shove, Pantzar, and Watson 2012; Warde 2005) and has also been seen in HCI research (Entwistle et al. 2015; Kuutti and Bannon 2014). Schwartz et al. (2013) conducted a phenomenological inquiry pointing out how feedback technologies can be designed to support the practice of making energy consumption accountable. Kuijer, A. d. Jong, and Eijk (2013) used a social practice lens to investigate designs that act as material element allowing new practices of bodily hygiene to emerge. This theoretical frame was used to guide work on food waste practices and technology designs to reduce waste (Ganglbauer, Fitzpatrick, and Güldenpfennig 2015), design considerations for creating technology supporting self-care of Parkinson's patients (Nunes 2015) or to inform ICT designs on supporting other modes of transportation (Hasselqvist, Hesselgren, and Bogdan 2016).

8.4.2 Values in Design

Within the viewpoint of a third paradigm in HCI, the evaluation of a systems success cannot be primarily grounded in universally valid measures. We must rather ask what it means to be "good" or "a success", i.e. what values we bring to design and research (Harrison, Sengers, and Tatar 2011; Ferrario et al. 2017). My studies presented in this thesis carry the value that cycling is a "good" transportation method, especially when compared to motorised car-based ones. Cycling is therefore an action contributing to environmental sustainability worth being promoted.

Furthermore, I implicitly assumed that learning, skill development, and personal growth are desirable attributes. I also respect individual agency by giving people the autonomy to take this technology up and use it or not. However, this as well represents imposed values that derive from my perspective but do not represent a true statement. Furthermore, while trying to critically reflect on my own subjective perspective (see Chapter 3), I most likely still projected a scholastic bias towards the people I have studied (Strengers 2014).

8.4.3 Support Systems for Everyday Practices

The results from Chapter 4 and Chapter 5 indicate that technology can affect choices to cycle more often by introducing playful elements, as long as this is done within an existing social setting. Technology can be the tool to facilitate this social space, e.g., as done with the leader boards shown in Figure 5.4. This points to other areas where technology might be introduced to existing social settings to support the adoption of practices.

Studying such opportunities for technology design in the realm of transportation is still rare. A notable example is a study on car-free living families by Hasselqvist, Hesselgren, and Bogdan (2016), who studied three families who replaced their cars with different combinations of light electric vehicles for one year. They thereby found the need for navigation and travel planning applications to support odd types of vehicles and more criteria than travel time, the need for offering and connecting to transportation services, and the need for receiving help in a structured way without bothering or the feeling of owing the helpers a favour in return. The latter could be tackled by a design where, e.g., hidden commitments are avoided to prevent a feeling of owing someone. The hierarchical levels of actions for cycling introduced in Chapter 7 provide pointers to study similar opportunities.

Furthermore, in the sequence of the case studies I designed technology probes based on existing structures and processes: The evaluation of Bike to Work informed the design and evaluation of the Biking Tourney, the existing teaching programs for beginner cyclists informed the Virtual Cycling Coach. Grounding the technology probes in "proven" setups that way helped to concentrate on the problem tackled in this thesis, i.e. asking how to use *technology* to support the uptake of utilitarian cycling.

8.4.4 Rebound Effects

When designing for environmentally sustainable practices, total effects, including rebound effects, should be considered. For environmental sustainability, CO_{2e} emissions can be a way for assessing those effects, while a complete assessment could include, e.g., overall resource consumption, effects on biodiversity, or associated pollution. In a recent review, areas for climate action have been ranked according to their impact (Wynes and Nicholas 2017). Areas with a high impact on an individual's carbon footprint (> 0.8 tCO_{2e} annually) are personal transportation, the choice of energy provider, and diet. Household practices fall into an area of moderate impact (0.2-0.8 tCO_{2e} annually). Among those are laundry practices – washing laundry at cooler temperatures or hanging dry clothes – and recycling waste. The low impact area (<0.2 tCO_{2e} annually) covers aspects such as upgrading one's light bulbs, minimising waste, or buying organic food. In general, this indicates the potential of ICT to affect greenhouse gas emissions from in everyday practices.

As shown in the case studies I (Frequent Biking Challenge), IV (Bike to work) and V (Biking Tourney), information and communication technology can facilitate motivation to use a bicycle more often, thereby affecting a lifestyle area with a high ecological impact. However, indirect rebound effects need to be considered to give a complete answer regarding environmental benefits. Such effects occur when cost savings increase consumption of other goods and services that offset the initially generated environmental benefits (Hertwich 2005). For example, the effect of an ICT artefact that introduces an increase in bicycle usage may also lead to cost savings. The net benefit is lost if this saved money is then used, e.g., to buy a long-haul flight to a holiday destination. Hence, to fully assess the impact of an ICT-based innovation on environmental sustainability, an analysis of all associated increases and decreases in resource consumption would be needed.[3] Hence, while environmental concerns are a motivation for many to start or increase their use of bicycles (see Chapter 5), as researchers or designers, we have to be careful in assessing the environmental impact of any reported change in the choices users of any artefact make.

8.4.5 Reflection on Behavior Change

As shown in previous chapters 2 and 7, a substantial body of research in HCI for transportation follows a behaviour change agenda. The project that my thesis work has also been originally a part of that stream with an implicit goal of "individual behaviour change". A moral question is thereby *who* wants that change. Is it a person looking for a system to support them in changing their behaviour, or is it the designer or researcher who wants to change someone else? Imposing such a change seems like a paternalistic act that begs the moral question of who should decide on whom to change what (Thaler and Sunstein 2009). Most behaviour change designs carry an inherent approach to promoting

[3]As an example: In recent years, ICT enabled a lean experience of car-sharing and ride-hailing services. A customer can locate, book, unlock, etc., a car using her smartphone. This makes such services more convenient than traditional rental cars or even owning a car, particularly in urban areas. There are ongoing debates on the overall environmental effects of introducing such services (Firnkorn and Müller 2011), as it is difficult to measure if the environmental benefits of replacing owned cars by shared vehicles overall outweigh the negative impact of trips that shift from public transport or an active mobility option to a car-sharing vehicle. (T. Chen and Kockelman 2016; E. Martin and Shaheen 2011) Even if the total amount of vehicle miles travelled decreases, indirect rebound effects might render such benefits irrelevant.

change with them. These could be authoritarian systems, i.e., ones that are telling people what to do. Coercion could be a mode of interaction, e.g., within workplaces where a change is mandated. A paternalistic system would know what to do best and decide to do so, whereas a system of libertarian paternalism (Thaler and Sunstein 2009) would opt to set the defaults to the supposedly best outcome. The relationship between the system and its user could also be one of support, e.g., by offering virtual coaches to self-guided eHealth interventions (Scholten, Kelders, and Gemert-Pijnen 2017) or through supporting reflection (Fleck and Fitzpatrick 2010). From the former to the latter, the orientation towards the user of a technology changes, from being the problem to helping solve the user's problems (DiSalvo, Sengers, and Brynjarsdóttir 2010). This should also involve to understand the broader context in which a technology will be used (Hekler et al. 2013).

Societal problems, such as environmental sustainability, urban planning, or public health, should not be primarily seen as choices by individuals. A social practice lens is one way of understanding such choices as just the most visible aspect of underlying structures. It has been critiqued before that a view focused on attitudes, behaviors and choices by individuals is not suitable to understand societal processes at large (Shove 2010). As for HCI, the individual is and will be continue to be a central point of interest. However, I argue that when addressing environmental sustainability in HCI we need to acknowledge that sustainable development should and probably only can be achieved through collective political action, leaving persuasion to arguments about policy decisions and not the technology used by individuals (Brynjarsdottir et al. 2012).

8.5 Limitations

The turn to the wild in HCI represents a shift towards technologies "designed to enhance and become part of the everydayness of life" (Rogers 2012). My work sits firmly within that. Such *in situ* studies are good at capturing the context of use but are expensive and difficult to conduct (Rogers et al. 2007). This also resulted in the following methodological limitations to this thesis' findings:

- **Longer-term use:** As existing research points to the role of competencies for utilitarian cycling (Johnson and Margolis 2013; Telfer et al. 2006), a larger scale, longitudinal study on the presented interventions would further contribute to knowledge and increase dependability and confirmability of the findings. The technology probes presented in the case studies have been evaluated on relatively short time scales. Hence, I often studied immediate changes in action and short-term outcomes. An example is the "Keymoment" design, where a "little troublemaker" is used to encourage the use of a bicycle instead of a car (Laschke et al. 2014). However, few studies assess the longer-term impact of an ICT design to promote sustainability. Particularly when viewing ICT designs through the lens of social practices – where existing ones change, and new ones emerge only over time – the question becomes how such longer-term changes in practices can be captured within research timeframes. From a social practice perspective, this design artefact could be a material element necessary for the emergence of new situated learning practices.

- **Qualitative insights:** The findings from the data shown in this thesis are descriptions of observed phenomena, which are situated in specific contexts. The conceptual framework established in the previous chapter provides a structure for future research and design. However, testing and evaluating clear causal links – e.g., by conducting large scale randomised controlled trials – was beyond the scope of this thesis.

- **Capturing experiences:** There is also a substantial difference between riding a bicycle and thinking about doing so. Being mindful of this difference and acknowledging this difference can help to design more meaningful technology.

- **Capturing automatic and reflective cognitive processes**: There is a methodological challenge of assessing of automaticity vs. reflective thinking. Methods such as interviews or surveys are likely to involve rational, reflective and critical thinking by study participants. This makes it difficult to directly capture routines and automatisms. A method for getting closer to those can be observations, such as doing in person observations or creating video recordings as done in case studies IV and V.

- **Experiencing and remembering self:** Prior research showed that our memory of certain episodes does not provide an accurate representation of our experiences Kahneman (2011). In a retrospective evaluative frame of mind, unpleasant emotions are more likely to be recalled than pleasant ones (Miron-Shatz, A. Stone, and Kahneman 2009). This effect could also be confirmed across age groups and gender (Neubauer et al. 2020). This memory-experience gap for ratings of emotions has also been shown in HCI (Bruun and Ahm 2015). Hence, what we can recall of any episode is neither an accurate nor a complete representation of our experience. As shown in the case studies above, it is often a small but very unpleasant segment of one's route or a single bad experience while cycling that can affect the judgment and motivation to use the bicycle. To better understand the use of information and communication technology for cycling, a more detailed description of experiences and the memories thereof would be beneficial.

- **Biases in the presented studies:** There is most likely a self-selection bias for these campaigns and studies to be joined by people that intend to adopt cycling.

- **Secondary effects remain unexplored:** Short-term changes account only for individuals taking part in studies. They thus leave out additional effects, e.g., due to spread of ideas or social learning, or changes in the social practice due to a new technology.

There are also limitations originating from the constructivist epistemology underpinning this thesis. My colleagues and I as investigators were interactively linked with the investigated object. The answers to the research questions emerged from that link. In accepting that philosophical stance, the findings presented above are then understood as being *created* over the course of the research (Guba and Lincoln 1994). This stance also makes the distinction between ontology and epistemology less clear, i.e., what is to be known and the relationship between the investigator who wants to know becomes entangled. The findings presented in this theses hence are a reconstruction created by me to provide an understanding of the role technology can play in supporting cyclists. By understanding findings like this, the research presented here offers a "more informed and sophisticated reconstruction" (Guba and Lincoln 1994) on promoting the uptake of utilitarian cycling through information and communication technology.

8.6 Future Work

The research in this thesis spans across multiple disciplines. Particularly, HCI and transportation research were bridged. There is a tendency in HCI research for newness, i.e. favouring contributions that provide "new knowledge" (Wobbrock and Kientz 2016). This can lead to little effort to reproduce existing studies to contribute by confirming and expanding previous findings. However, transportation research mainly follows a post-positivistic philosophy that would suggest reproducing the presented studies on a larger scale, with an experimental randomised controlled trial setup. This could provide a description of statistically supported causal relations. Such further research can help to quantify and validate the findings presented in this thesis.

As for ICT designed for choices, research in cycling has similarities to other realms concerned with the interplay of technology and everyday practices. Given the body of research available, future research could explicitly tackle the methodological limitations shown above. Furthermore, many existing software applications include social or other motivational features to motivate users to stay physically active by cycling. However, there are still few published studies on their effectiveness.

As for planning practices, future research on navigational guidance could include insights from this thesis: Navigation algorithms could integrate the complexity of route segments as an attribute when computing routes that are best suited to a cyclist's level of competencies. Apps used for navigation could also integrate aspects derived from the coaching approach. This could be particularly helpful to beginning cyclists. Applications such as komoot[4] do offer advanced route planning features that include the road category, surface types, elevation data and much more. It also includes route segments that are highlighted by other users to indicate interesting or enjoyable paths. Future research could investigate the effect of such features.

Current advances in the field of autonomous vehicles could inform studies on assisting

[4] https://www.komoot.de

systems for cyclists. While the bicycle arguably possesses the quality of inherent simplicity, there is no reason not to embody more technology in the future. Research should therefore also explore human-computer-bicycle interactions that derive from bringing sophisticated technology to the bicycle. Those could be automated warnings – e.g., when driving too close to parked cars –, emergency brake systems, or blind spot warnings. Work by Matviienko, Ananthanarayan, Sadeghian Borojeni, et al. (2018) represents the first foray into that topic. Future studies in this realm could investigate human-bicycle cooperation, similar to how this has been done for motorised vehicles (Wintersberger 2020).

CHAPTER 9

Conclusion

This thesis aimed to connect the design of information and communication technology for supporting the uptake of cycling within everyday settings with an understanding of the lived experiences within utilitarian cycling. A range of empirical case studies served to inform a conceptual framework to structure the understanding of HCI and utilitarian cycling. These case studies did also provide examples of how information and communication technologies can be meaningful in promoting the uptake of utilitarian cycling. The discussions outlined the limitations of such approaches, particularly around dependencies on cycling infrastructures, competencies, and policy. In doing so, this thesis offers multiple contributions listed below. The type of contribution follows the nomenclature introduced by Wobbrock and Kientz (2016).

This thesis makes these primary contributions:

- An understanding of cyclists experiences within complex real-world contexts. This can inform the design of information and communication technology for a meaningful *in situ* support. *(Case Study III (Bike Buddy Program), Case Study VI (Teaching and Coaching for Beginning Cyclists), and Case Study VII (Virtual Cycling Coach) – empirical contribution)*
- A description of the interplay between systems for motivational support and choices and the role of technology for everyday active mobility. *(case studies I (Frequent Biking Challenge), IV (Bike to work), and V (Biking Tourney) – empirical contribution)*
- A conceptual framework that offers a structure for HCI and utilitarian cycling, thereby unpacking the social practice of cycling into a structure of sub-practices. These span from abstract and decontextualised to specific and contextualised practices, in each of which ICT can get integrated. This framework can help future

researchers to reflect on different dimensions of (utilitarian) cycling. *(Chapter 7 – theoretical contribution)*

Beyond those, it offers these secondary contributions:

- Discussion and comparison of ICT for choices and in-the-moment interaction in the realm of utilitarian cycling. *(theoretical contribution)*
- The effect of technology interventions grounded in gamification and social collaboration on transportation choices. *(Chapter 5 – empirical contribution)*
- Understanding professional support for novice cyclists and how they can inform the design of in-the-moment support. *(Chapter 6 – empirical contribution)*
- Description of a prototype of the Virtual Cycling Coach. There have not been studies on a similar artefact before. *(Chapter 6 – contribution by artefact)*
- A description of Wizard of Oz prototyping in-the-wild for bicycles to increase the ecological validity for situated interventions. *(Chapter 6 – methodological contribution)*

Information and communication technology has become both a substantial and pervasive part of our everyday lives. There are plenty of possible systems that could support, motivate, engage or protect cyclists. Some of those might seem too far out there. However, given how technology is getting advanced continuously, some of those systems might one day become part of our everyday rides.

I was motivated to do this work by the wish to use technology for the greater good. I set out to investigate ways to empower individuals through information and communication technology when taking up cycling and therefore explored systems for cyclists that are embedded in the fuzzy world of everyday living. Recently, there was an effort to bring together a group of researchers with similar interests in HCI for cycling at ACM CHI 2021. I thus finish this thesis hoping that it can help fellow researchers and designers that will work in this domain in the future.

List of Figures

List of Tables

Bibliography

Aarts, Henk and A.P. Dijksterhuis (2000). „The automatic activation of goal-directed behaviour: The case of travel habit". In: *Journal of Environmental Psychology* 20.1, pp. 75–82. ISSN: 0272-4944. DOI: 10.1006/jevp.1999.0156.

Aarts, Henk, Bas Verplanken, and Ad van Knippenberg (1998). „Predicting Behavior From Actions in the Past: Repeated Decision Making or a Matter of Habit?" In: *Journal of Applied Social Psychology* 28.15, pp. 1355–1374. ISSN: 1559-1816. DOI: 10.1111/j.1559-1816.1998.tb01681.x.

Al-Abbadey, Miznah et al. (2021). „Mobile health apps: An exploration of user-generated reviews in Google Play Store on a physical activity application". In: *DIGITAL HEALTH* 7. Publisher: SAGE Publications Ltd. ISSN: 2055-2076. DOI: 10.1177/20552076211014988.

Aldred, Rachel and Katrina Jungnickel (2014). „Why culture matters for transport policy: the case of cycling in the UK". In: *Journal of Transport Geography* 34, pp. 78–87. ISSN: 0966-6923. DOI: 10.1016/j.jtrangeo.2013.11.004.

Allen, T. M., H. Lunenfeld, and G. J. Alexander (1971). „Driver information needs". In: *Highway research record* 366.366, pp. 102–115.

Andres, Josh et al. (2019). „"Co-riding With My eBike to Get Green Lights"". In: *Proceedings of the 2019 on Designing Interactive Systems Conference*. DIS '19. New York, NY, USA: Association for Computing Machinery, pp. 1251–1263. ISBN: 978-1-4503-5850-7. DOI: 10.1145/3322276.3322307.

Ariely, Dan (2010). *Predictably Irrational: The Hidden Forces That Shape Our Decisions*. Harper Perennial. ISBN: 978-0-06-135324-6.

Barnes, Gary, Kristen Thompson, and Kevin Krizek (2006). „A longitudinal analysis of the effect of bicycle facilities on commute mode share". In: *85th Annual Meeting of the Transportation Research Board. Transportation Research Board*. Washington, DC.

Bial, Dominik et al. (2012). „Improving Cyclists Training with Tactile Feedback on Feet". In: *Haptic and Audio Interaction Design*. Ed. by Charlotte Magnusson, Delphine Szymczak, and Stephen Brewster. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, pp. 41–50. ISBN: 978-3-642-32796-4. DOI: 10.1007/978-3-642-32796-4_5.

Bødker, Susanne (2015). „Third-wave HCI, 10 years later—participation and sharing". In: *Interactions* 22.5, pp. 24–31. ISSN: 1072-5520. DOI: 10.1145/2804405.

Braun, Virginia and Victoria Clarke (2006). „Using thematic analysis in psychology“. In: *Qualitative research in psychology* 3.2, pp. 77–101. DOI: 10.1191/1478088706qp063oa.

— (2019). „Reflecting on reflexive thematic analysis“. In: *Qualitative Research in Sport, Exercise and Health* 11.4, pp. 589–597. ISSN: 2159-676X. DOI: 10.1080/2159676X.2019.1628806.

Brisswalter, Jeanick, Maya Collardeau, and Arcelin René (2012). „Effects of Acute Physical Exercise Characteristics on Cognitive Performance“. In: *Sports Medicine* 32.9, pp. 555–566. ISSN: 0112-1642, 1179-2035. DOI: 10.2165/00007256-200232090-00002.

Broll, Gregor et al. (2012). „tripzoom: An App to Improve your Mobility Behavior“. In: *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*. MUM '12. New York, NY, USA: Association for Computing Machinery, pp. 1–4. ISBN: 978-1-4503-1815-0. DOI: 10.1145/2406367.2406436.

Brown, Lawrence D., T. Tony Cai, and Anirban DasGupta (2001). „Interval Estimation for a Binomial Proportion“. In: *Statistical Science* 16.2, pp. 101–133. ISSN: 0883-4237, 2168-8745. DOI: 10.1214/ss/1009213286.

Bruun, Anders and Simon Ahm (2015). „Mind the Gap! Comparing Retrospective and Concurrent Ratings of Emotion in User Experience Evaluation“. In: *Human-Computer Interaction – INTERACT 2015*. Ed. by Julio Abascal et al. Lecture Notes in Computer Science. Cham: Springer International Publishing, pp. 237–254. ISBN: 978-3-319-22701-6. DOI: 10.1007/978-3-319-22701-6_17.

Brynjarsdottir, Hronn et al. (2012). „Sustainably unpersuaded: How persuasion narrows our vision of sustainability“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '12. New York, NY, USA: Association for Computing Machinery, pp. 947–956. ISBN: 978-1-4503-1015-4. DOI: 10.1145/2207676.2208539.

Carroll, J. M. and W. A. Kellogg (1989). „Artifact as theory-nexus: hermeneutics meets theory-based design“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '89. New York, NY, USA: Association for Computing Machinery, pp. 7–14. ISBN: 978-0-89791-301-0. DOI: 10.1145/67449.67452.

Celis-Morales, Carlos A. et al. (2017). „Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study“. In: *BMJ* 357.10. ISSN: 0959-8138. DOI: 10.1136/bmj.j1456.

Chen, T.D. and K.M. Kockelman (2016). „Carsharing's life-cycle impacts on energy use and greenhouse gas emissions“. In: *Transportation Research Part D: Transport and Environment* 47, pp. 276–284. ISSN: 1361-9209. DOI: 10.1016/j.trd.2016.05.012.

Chen, Wu et al. (Aug. 18, 2022). „Historical patterns and sustainability implications of worldwide bicycle ownership and use“. In: *Communications Earth & Environment* 3.1. Number: 1 Publisher: Nature Publishing Group, pp. 1–9. ISSN: 2662-4435. DOI: 10.1038/s43247-022-00497-4.

Cheng, Yun-Maw and Chao-Lung Lee (2015). „Persuasive and engaging design of a Smartphone App for cycle commuting“. In: *mUX: The Journal of Mobile User Experience* 4.1, p. 1. ISSN: 2196-873X. DOI: 10.1186/s13678-015-0001-9.

Cialdini, R. B. (2007). *Influence: The Psychology of Persuasion*. HarperCollins ebooks.
Clopper, C. J. and Egon S. Pearson (1934). „The use of confidence or fiducial limits illustrated in the case of the binomial". In: *Biometrika* 26.4, pp. 404–413. DOI: 10.1093/biomet/26.4.404.
Crawford, Sharinne (2011). „Promoting active transport to school: evaluation of the Ride2School program". PhD thesis. Deakin University.
Crist, Katie et al. (2018). „Fear Factor: Level of Traffic Stress and GPS Assessed Cycling Routes". In: *Journal of Transportation Technologies* 9.1, pp. 14–30. DOI: 10.4236/jtts.2019.91002.
Dancu, Alexandru, Zlatko Franjcic, and Morten Fjeld (2014). „Smart flashlight: map navigation using a bike-mounted projector". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '14. New York, NY, USA: Association for Computing Machinery, pp. 3627–3630. ISBN: 978-1-4503-2473-1. DOI: 10.1145/2556288.2557289.
Dancu, Alexandru, Velko Vechev, et al. (2015). „Gesture Bike: Examining Projection Surfaces and Turn Signal Systems for Urban Cycling". In: *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces - ITS '15*. the 2015 International Conference. Madeira, Portugal: ACM Press, pp. 151–159. ISBN: 978-1-4503-3899-8. DOI: 10.1145/2817721.2817748.
Denzin, Norman K (2009). *Sociological methods: a sourcebook*. New Brunswick; London: Aldine Transaction. ISBN: 978-0-202-30840-1.
Deterding, Sebastian et al. (2011). „From Game Design Elements to Gamefulness: Defining "Gamification"". In: *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*. MindTrek '11. New York, NY, USA: ACM, pp. 9–15. ISBN: 978-1-4503-0816-8. DOI: 10.1145/2181037.2181040.
Dickinson, Janet E et al. (2003). „Employer travel plans, cycling and gender: will travel plan measures improve the outlook for cycling to work in the UK?" In: *Transportation Research Part D: Transport and Environment* 8.1, pp. 53–67. ISSN: 1361-9209. DOI: 10.1016/S1361-9209(02)00018-4.
Dill, Jennifer and Nathan McNeil (2016). „Revisiting the Four Types of Cyclists: Findings from a National Survey". In: *Transportation Research Record* 2587.1. Publisher: SAGE Publications Inc, pp. 90–99. ISSN: 0361-1981. DOI: 10.3141/2587-11.
Dill, Jennifer and Kim Voros (2007). „Factors affecting bicycling demand: initial survey findings from the Portland, Oregon, region". In: *Transportation Research Record: Journal of the Transportation Research Board* 2031, pp. 9–17. DOI: 10.3141/2031-02.
Dinu, Monica et al. (2019). „Active Commuting and Multiple Health Outcomes: A Systematic Review and Meta-Analysis". In: *Sports Medicine* 49.3, pp. 437–452. ISSN: 1179-2035. DOI: 10.1007/s40279-018-1023-0.
Disalvo, Carl, Johan Redström, and Matt Watson (2008). „Commentaries on the Special Issue on Practice-oriented Approaches to Sustainable HCI". In: *ACM Trans. Comput.-Hum. Interact.* 20.4, 26:1–26:15. ISSN: 1073-0516. DOI: 10.1145/2509404.2509408.

DiSalvo, Carl, Phoebe Sengers, and Hrönn Brynjarsdóttir (2010). „Mapping the Landscape of Sustainable HCI“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '10. New York, NY, USA: ACM, pp. 1975–1984. ISBN: 978-1-60558-929-9. DOI: 10.1145/1753326.1753625.

Dourish, Paul (2001). *Where the Action Is: The Foundations of Embodied Interaction*. ISBN: 978-0-262-04196-6.

Ducheyne, Fabian, Ilse De Bourdeaudhuij, Matthieu Lenoir, and Greet Cardon (2013). „Does a cycle training course improve cycling skills in children?“ In: *Accident Analysis & Prevention* 59, pp. 38–45. ISSN: 0001-4575. DOI: 10.1016/j.aap.2013.05.018.

Ducheyne, Fabian, Ilse De Bourdeaudhuij, Matthieu Lenoir, Heleen Spittaels, et al. (2013). „Children's cycling skills: Development of a test and determination of individual and environmental correlates“. In: *Accident Analysis & Prevention* 50, pp. 688–697. ISSN: 0001-4575. DOI: 10.1016/j.aap.2012.06.021.

Engel, Andreas K. et al. (2013). „Where's the action? The pragmatic turn in cognitive science“. In: *Trends in cognitive sciences* 17.5, pp. 202–209. DOI: 10.1016/j.tics.2013.03.006.

Entwistle, Johanne Mose et al. (2015). „Beyond the Individual: The Contextual Wheel of Practice as a Research Framework for Sustainable HCI“. In: *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. CHI '15. New York, NY, USA: Association for Computing Machinery, pp. 1125–1134. ISBN: 978-1-4503-3145-6. DOI: 10.1145/2702123.2702232.

Evans, Jonathan (2008). „Dual-Processing Accounts of Reasoning, Judgment, and Social Cognition“. In: *Annual Review of Psychology* 59.1, pp. 255–278. DOI: 10.1146/annurev.psych.59.103006.093629.

Evans, Jonathan and Keith E. Stanovich (2013). „Dual-process theories of higher cognition advancing the debate“. In: *Perspectives on Psychological Science* 8.3, pp. 223–241. DOI: 10.1177/1745691612460685.

Ferrario, Maria Angela et al. (2017). „Values in Computing“. In: *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. CHI EA '17. New York, NY, USA: ACM, pp. 660–667. ISBN: 978-1-4503-4656-6. DOI: 10.1145/3027063.3027067.

Festinger, Leon (1962). *A theory of cognitive dissonance*. Vol. 2. Stanford University Press.

— (1964). *Conflict, decision, and dissonance*. Vol. 3. Stanford University Press.

Firnkorn, Jörg and Martin Müller (2011). „What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm“. In: *Ecological Economics* 70.8, pp. 1519–1528. ISSN: 0921-8009. DOI: 10.1016/j.ecolecon.2011.03.014.

Fishman, Elliot (2016). „Cycling as transport“. In: *Transport Reviews* 36.1, pp. 1–8. ISSN: 0144-1647. DOI: 10.1080/01441647.2015.1114271.

Fleck, Rowanne and Geraldine Fitzpatrick (2010). „Reflecting on Reflection: Framing a Design Landscape“. In: *Proceedings of the 22Nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*.

OZCHI ’10. New York, NY, USA: ACM, pp. 216–223. ISBN: 978-1-4503-0502-0. DOI: 10.1145/1952222.1952269.

Flüchter, Kristina, Felix Wortmann, and Elgar Fleisch (2014). „Digital commuting: the effect of social normative feedback on e-bike commuting – evidence from a field study“. In: *Proceedings of the European Conference on Information Systems (ECIS) 2014*. Tel Aviv, Israel. ISBN: 978-0-9915567-0-0. URL: https://aisel.aisnet.org/ecis2014/proceedings/track01/5/.

Fogg, B. J. (2003). *Persuasive Technology: Using Computers to Change what We Think and Do*. Morgan Kaufmann. 316 pp. ISBN: 978-1-55860-643-2.

Fraser, Simon D. S. and Karen Lock (2011). „Cycling for transport and public health: a systematic review of the effect of the environment on cycling“. In: *The European Journal of Public Health* 21.6, pp. 738–743. ISSN: 1101-1262, 1464-360X. DOI: 10.1093/eurpub/ckq145.

Frauenberger, Christopher (2019). „Entanglement HCI The Next Wave?“ In: *ACM Transactions on Computer-Human Interaction* 27.1, 2:1–2:27. ISSN: 1073-0516. DOI: 10.1145/3364998.

Froehlich, Jon, Tawanna Dillahunt, et al. (2009). „UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI ’09. New York, NY, USA: ACM, pp. 1043–1052. ISBN: 978-1-60558-246-7. DOI: 10.1145/1518701.1518861.

Froehlich, Jon, Leah Findlater, and James Landay (2010). „The Design of Eco-feedback Technology“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI ’10. New York, NY, USA: ACM, pp. 1999–2008. ISBN: 978-1-60558-929-9. DOI: 10.1145/1753326.1753629.

Fuller, Ray (2005). „Towards a general theory of driver behaviour“. In: *Accident Analysis & Prevention* 37.3, pp. 461–472. ISSN: 0001-4575. DOI: 10.1016/j.aap.2004.11.003.

Füssl, Elisabeth and Juliane Haupt (2016). „Understanding cyclist identity and related interaction strategies. A novel approach to traffic research“. In: *Transportation Research Part F: Traffic Psychology and Behaviour*. ISSN: 1369-8478. DOI: 10.1016/j.trf.2016.08.003.

Gabrielli, Silvia, Paula Forbes, et al. (2014). „Design challenges in motivating change for sustainable urban mobility“. In: *Computers in Human Behavior* 41, pp. 416–423. DOI: 10.1016/j.chb.2014.05.026.

Gabrielli, Silvia and Rosa Maimone (2013). „Are Change Strategies Affecting Users’ Transportation Choices?“ In: *Proceedings of the Biannual Conference of the Italian Chapter of SIGCHI*. CHItaly ’13. New York, NY, USA: ACM, 9:1–9:4. ISBN: 978-1-4503-2061-0. DOI: 10.1145/2499149.2499155.

Gabrielli, Silvia, Rosa Maimone, et al. (2013). „Designing Motivational Features for Sustainable Urban Mobility“. In: *CHI ’13 Extended Abstracts on Human Factors in Computing Systems*. CHI EA ’13. New York, NY, USA: ACM, pp. 1461–1466. ISBN: 978-1-4503-1952-2. DOI: 10.1145/2468356.2468617.

Ganglbauer, Eva, Geraldine Fitzpatrick, and Rob Comber (2013). „Negotiating food waste: Using a practice lens to inform design“. In: *ACM Transactions on Computer-Human Interaction* 20.2, 11:1–11:25. ISSN: 1073-0516. DOI: 10.1145/2463579.2463582.

Ganglbauer, Eva, Geraldine Fitzpatrick, and Florian Güldenpfennig (2015). „Why and What Did We Throw out?: Probing on Reflection Through the Food Waste Diary“. In: *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. CHI ’15. New York, NY, USA: ACM, pp. 1105–1114. ISBN: 978-1-4503-3145-6. DOI: 10.1145/2702123.2702284.

Gatersleben, Birgitta and Katherine M. Appleton (2007). „Contemplating cycling to work: Attitudes and perceptions in different stages of change“. In: *Transportation Research Part A: Policy and Practice* 41.4, pp. 302–312. ISSN: 0965-8564. DOI: 10.1016/j.tra.2006.09.002.

Geissler, Harald et al. (2014). „E-Coaching: Conceptual and Empirical Findings of a Virtual Coaching Programme.“ In: *International Journal of Evidence Based Coaching & Mentoring* 12.2. ISSN: 1741-8305. URL: https://search.informit.org/doi/10.3316/informit.706758416429391.

Goodman, Anna, Esther M. F. van Sluijs, and David Ogilvie (2015). „Cycle training for children: Which schools offer it and who takes part?“ In: *Journal of Transport & Health* 2.4, pp. 512–521. ISSN: 2214-1405. DOI: 10.1016/j.jth.2015.07.002.

Gössling, Stefan and Andy S. Choi (2015). „Transport transitions in Copenhagen: Comparing the cost of cars and bicycles“. In: *Ecological Economics* 113, pp. 106–113. ISSN: 0921-8009. DOI: 10.1016/j.ecolecon.2015.03.006.

Götzenbrucker, G. and M. Köhl (2012). „Advanced traveller information systems for intelligent future mobility: the case of ‘AnachB’ in Vienna“. In: *IET Intelligent Transport Systems* 6.4. Publisher: IET Digital Library, pp. 494–501. ISSN: 1751-9578. DOI: 10.1049/iet-its.2011.0151.

Grant, Anthony M. (2003). „The impact of life coaching on goal attainment, metacognition and mental health“. In: *Social Behavior and Personality: An International Journal* 31.3, pp. 253–264. ISSN: 1179-6391. DOI: 10.2224/sbp.2003.31.3.253.

Green, Paul and Lisa Wei-Haas (1985). „The Rapid Development of User Interfaces: Experience with the Wizard of OZ Method“. In: *Proceedings of the Human Factors Society Annual Meeting* 29.5, pp. 470–474. ISSN: 0163-5182. DOI: 10.1177/154193128502900515.

Guba, Egon G. and Yvonna S. Lincoln (1994). „Competing Paradigms in Qualitative Research“. In: *The SAGE Handbook of Qualitative Research*. Red. by Yvonna S. Lincoln and Norman K. Denzin. Thousand Oaks: Sage, pp. 105–117.

Guerin, Bernard (2010). *Social facilitation*. Wiley Online Library. URL: https://doi.org/10.1002/9780470479216.corpsy0890.

Guo, Jessica Y., Chandra R. Bhat, and Rachel B. Copperman (2007). „Effect of the built environment on motorized and nonmotorized trip making: substitutive, complementary, or synergistic?“ In: *Transportation Research Record* 2010.1, pp. 1–11. DOI: 10.3141/2010-01.

Habibovic, A. et al. (2016). „Evaluating interactions with non-existing automated vehicles: three Wizard of Oz approaches“. In: *2016 IEEE Intelligent Vehicles Symposium (IV)*. 2016 IEEE Intelligent Vehicles Symposium (IV), pp. 32–37. DOI: 10.1109/IVS.2016.7535360.

Hamilton, David (1994). „Traditions, preferences, and postures in applied qualitative research.“ In: *Handbook of qualitative research*. Ed. by Norman K Denzin and Yvonna S. Lincoln. Sage Publications, Inc., pp. 60–69.

Haraway, Donna (1988). „Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective“. In: *Feminist Studies* 14.3. Publisher: Feminist Studies, Inc., pp. 575–599. ISSN: 0046-3663. DOI: 10.2307/3178066.

Harel, David, Assaf Marron, and Joseph Sifakis (2020). „Autonomics: In search of a foundation for next-generation autonomous systems“. In: *Proceedings of the National Academy of Sciences* 117.30, pp. 17491–17498. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.2003162117.

Harmon-Jones, Eddie and Cindy Harmon-Jones (2007). „Cognitive dissonance theory after 50 years of development“. In: *Zeitschrift für Sozialpsychologie* 38.1, pp. 7–16. DOI: 10.1024/0044-3514.38.1.7.

Harrison, Steve, Phoebe Sengers, and Deborah Tatar (2011). „Making epistemological trouble: Third-paradigm HCI as successor science“. In: *Interacting with Computers* 23.5, pp. 385–392. ISSN: 1873-7951. DOI: 10.1016/j.intcom.2011.03.005.

Harrison, Steve, Deborah Tatar, and Phoebe Sengers (2007). „The Three Paradigms of HCI“. In: *Alt. Chi. Session at the SIGCHI Conference on human factors in computing systems San Jose, California, USA*, pp. 1–18.

Hasselqvist, Hanna, Mia Hesselgren, and Cristian Bogdan (2016). „Challenging the Car Norm: Opportunities for ICT to Support Sustainable Transportation Practices“. In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. CHI ’16. New York, NY, USA: Association for Computing Machinery, pp. 1300–1311. ISBN: 978-1-4503-3362-7. DOI: 10.1145/2858036.2858468.

Haworth, Narelle and Amy Schramm (2011). „How do level of experience, purpose for riding, and preference for facilities affect location of riding? Study of adult bicycle riders in Queensland, Australia“. In: *Transportation Research Record* 2247.1. Publisher: SAGE Publications Sage CA: Los Angeles, CA, pp. 17–23.

Heesch, Kristiann C. et al. (Feb. 9, 2017). „Cyclists’ perceptions of motorist harassment pre- to post-trial of the minimum passing distance road rule amendment in Queensland, Australia“. In: *Health Promotion Journal of Australia* 28.3. Publisher: CSIRO PUBLISHING, pp. 247–250. ISSN: 2201-1617, 2201-1617. DOI: 10.1071/HE16119.

Heidegger, Martin (1962). *Being and time: A translation of Sein und Zeit*. Oxford, UK: Blackwell.

Heinen, Eva, Bert van Wee, and Kees Maat (2010). „Commuting by Bicycle: An Overview of the Literature“. In: *Transport reviews* 30.1, pp. 59–96. DOI: 10.1080/01441640903187001.

Heinovski, Julian et al. (2019). „Modeling Cycling Behavior to Improve Bicyclists’ Safety at Intersections - A Networking Perspective“. In: *2019 IEEE 20th International*

Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), pp. 1–8. DOI: 10.1109/WoWMoM.2019.8793008.
Hekler, Eric B. et al. (2013). „Mind the Theoretical Gap: Interpreting, Using, and Developing Behavioral Theory in HCI Research“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '13. New York, NY, USA: Association for Computing Machinery, pp. 3307–3316. ISBN: 978-1-4503-1899-0. DOI: 10.1145/2470654.2466452.
Hernández–Melgarejo, G. et al. (2020). „Mechatronic design and implementation of a bicycle virtual reality system“. In: *ISA Transactions* 97, pp. 336–351. ISSN: 0019-0578. DOI: 10.1016/j.isatra.2019.08.002.
Herpers, R. et al. (2010). „FIVIS – A Bicycle Simulation System“. In: *World Congress on Medical Physics and Biomedical Engineering, September 7 - 12, 2009, Munich, Germany*. Ed. by Olaf Dössel and Wolfgang C. Schlegel. IFMBE Proceedings. Berlin, Heidelberg: Springer, pp. 2132–2135. ISBN: 978-3-642-03882-2. DOI: 10.1007/978-3-642-03882-2_566.
Hertwich, Edgar G. (2005). „Consumption and the Rebound Effect: An Industrial Ecology Perspective“. In: *Journal of Industrial Ecology* 9.1, pp. 85–98. ISSN: 1530-9290. DOI: 10.1162/1088198054084635.
Hunt, J. D. and J. E. Abraham (2006). „Influences on bicycle use“. In: *Transportation* 34.4, pp. 453–470. ISSN: 0049-4488, 1572-9435. DOI: 10.1007/s11116-006-9109-1.
IPCC (2021). „Summary for Policymakers“. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Ed. by V. Masson- Delmotte et al. Cambridge University Press. In Press. ISBN: 978-92-9169-158-6.
Johnson, Rebecca and Sam Margolis (2013). „A review of the effectiveness of adult cycle training in Tower Hamlets, London“. In: *Transport Policy* 30, pp. 254–261. ISSN: 0967-070X. DOI: 10.1016/j.tranpol.2013.09.005.
Jones, David EH (1970). „The Stability of The Bicycle“. In: *Physics Today* 23.4. Publisher: American Institute of Physics, pp. 34–40. URL: https://physicstoday.scitation.org/doi/10.1063/1.2364246.
Jylhä, Antti et al. (2013). „MatkaHupi: A Persuasive Mobile Application for Sustainable Mobility“. In: *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication*. UbiComp '13 Adjunct. New York, NY, USA: ACM, pp. 227–230. ISBN: 978-1-4503-2215-7. DOI: 10.1145/2494091.2494164.
Kahneman, Daniel (2011). *Thinking, fast and slow*. Penguin Group. ISBN: 978-0-14-103357-0.
Kant, Immanuel (1787). *Kritik der reinen Vernunft*. Nachdr. Stuttgart: Reclam.
Kazhamiakin, R. et al. (2015). „Using gamification to incentivize sustainable urban mobility“. In: *2015 IEEE First International Smart Cities Conference (ISC2)*. 2015 IEEE First International Smart Cities Conference (ISC2), pp. 1–6. DOI: 10.1109/ISC2.2015.7366196.
Kazhamiakin, Raman et al. (2021). „A Gamification Platform to Analyze and Influence Citizens' Daily Transportation Choices“. In: *IEEE Transactions on Intelligent Trans-*

portation Systems 22.4, pp. 2153–2167. ISSN: 1558-0016. DOI: 10.1109/TITS.2021.3049792.

Kelley, J. F. (1984). „An iterative design methodology for user-friendly natural language office information applications“. In: *ACM Transactions on Information Systems* 2.1, pp. 26–41. ISSN: 1046-8188. DOI: 10.1145/357417.357420.

Kirshner, Daniel (1980). „Some nonexplanations of bicycle stability“. In: *American Journal of Physics* 48.1, pp. 36–38. ISSN: 0002-9505. DOI: 10.1119/1.12246.

Klecha, Lisa and Francesco Gianni (2018). „Designing for Sustainable Urban Mobility Behaviour: A Systematic Review of the Literature“. In: *Citizen, Territory and Technologies: Smart Learning Contexts and Practices*. Ed. by Óscar Mealha, Monica Divitini, and Matthias Rehm. Smart Innovation, Systems and Technologies. Cham: Springer International Publishing, pp. 137–149. ISBN: 978-3-319-61322-2. DOI: 10.1007/978-3-319-61322-2_14.

Krug, Steve (2014). *Don't Make Me Think*. 3rd ed. New Riders. ISBN: 978-0-321-96551-6.

Kuijer, Lenneke and Annelise de Jong (2012). „Identifying design opportunities for reduced household resource consumption: exploring practices of thermal comfort“. In: *Journal of Design Research* 10.1, pp. 67–85. ISSN: 1748-3050. DOI: 10.1504/JDR.2012.046140.

Kuijer, Lenneke, Annelise de Jong, and Daan van Eijk (2013). „Practices As a Unit of Design: An Exploration of Theoretical Guidelines in a Study on Bathing“. In: *ACM Transactions on Computer-Human Interaction* 20.4, 21:1–21:22. ISSN: 1073-0516. DOI: 10.1145/2493382.

Kuutti, Kari (1996). „Activity theory as a potential framework for human-computer interaction research“. In: *Context and consciousness: Activity Theory and Human-Computer Interaction*. Ed. by Bonnie A. Naardi. Cambridge, MA: MIT Press, pp. 17–44. ISBN: 0-262-14058-6.

Kuutti, Kari and Liam J. Bannon (2014). „The Turn to Practice in HCI: Towards a Research Agenda“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '14. New York, NY, USA: Association for Computing Machinery, pp. 3543–3552. ISBN: 978-1-4503-2473-1. DOI: 10.1145/2556288.2557111.

Laschke, Matthias et al. (2014). „Keymoment: Initiating Behavior Change Through Friendly Friction“. In: *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. NordiCHI '14. New York, NY, USA: ACM, pp. 853–858. ISBN: 978-1-4503-2542-4. DOI: 10.1145/2639189.2670179.

Lee, Chao-Lung et al. (2010). „On the implications of sense of control over bicycling: design of a physical stamina-aware bike“. In: *Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction*. OZCHI '10. New York, NY, USA: Association for Computing Machinery, pp. 13–16. ISBN: 978-1-4503-0502-0. DOI: 10.1145/1952222.1952227.

Lete, Nerea, Andoni Beristain, and Alejandro García-Alonso (2020). „Survey on virtual coaching for older adults“. In: *Health Informatics Journal* 26.4. Publisher: SAGE Publications Ltd, pp. 3231–3249. ISSN: 1460-4582. DOI: 10.1177/1460458220926894.

Li, Yang, Jason I. Hong, and James A. Landay (2007). „Design Challenges and Principles for Wizard of Oz Testing of Location-Enhanced Applications“. In: *IEEE Pervasive Computing* 6.2. Conference Name: IEEE Pervasive Computing, pp. 70–75. ISSN: 1558-2590. DOI: 10.1109/MPRV.2007.28.

Magliocchetti, Daniele et al. (2012). „Ambient Intelligence on Personal Mobility Assistants for Sustainable Travel Choices.“ In: *Journal of Ubiquitous Systems & Pervasive Networks* 4.1, pp. 1–7. DOI: 10.5383/JUSPN.04.01.001.

Marshall, Joe, Alexandru Dancu, and Florian "Floyd" Mueller (2016). „Interaction in Motion: Designing Truly Mobile Interaction“. In: *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. DIS ’16. New York, NY, USA: Association for Computing Machinery, pp. 215–228. ISBN: 978-1-4503-4031-1. DOI: 10.1145/2901790.2901844.

Martin, Adam, Yevgeniy Goryakin, and Marc Suhrcke (2014). „Does active commuting improve psychological wellbeing? Longitudinal evidence from eighteen waves of the British Household Panel Survey“. In: *Preventive Medicine* 69, pp. 296–303. ISSN: 0091-7435. DOI: 10.1016/j.ypmed.2014.08.023.

Martin, Elliot and Susan Shaheen (2011). „The Impact of Carsharing on Public Transit and Non-Motorized Travel: An Exploration of North American Carsharing Survey Data“. In: *Energies* 4.11, pp. 2094–2114. DOI: 10.3390/en4112094.

Matviienko, Andrii, Swamy Ananthanarayan, Abdallah El Ali, et al. (2019). „NaviBike: Comparing Unimodal Navigation Cues for Child Cyclists“. In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. CHI ’19. New York, NY, USA: Association for Computing Machinery, pp. 1–12. ISBN: 978-1-4503-5970-2. DOI: 10.1145/3290605.3300850.

Matviienko, Andrii, Swamy Ananthanarayan, Shadan Sadeghian Borojeni, et al. (2018). „Augmenting bicycles and helmets with multimodal warnings for children“. In: *MobileHCI ’18: Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, pp. 1–13. DOI: 10.1145/3229434.3229479.

Maxwell, Joseph A. (2008). *Designing a qualitative study*. Vol. 2. The SAGE handbook of applied social research methods. URL: https://dx.doi.org/10.4135/9781483348858.

Meijaard, Jaap P. et al. (2007). „Linearized dynamics equations for the balance and steer of a bicycle: a benchmark and review“. In: *Proceedings of the Royal society A: mathematical, physical and engineering sciences* 463.2084, pp. 1955–1982. DOI: 10.1098/rspa.2007.1857.

Michahelles, Florian and Philipp Wintersberger (2021). „The Eternity Bike - Bringing Active Safety to the Bicycle“. In: *Cycling@CHI: Towards a Research Agenda for HCI in the Bike Lane at CHI ’21*. Yokohama, Japan, p. 5. URL: https://publik.tuwien.ac.at/files/publik_296009.pdf.

Michie, Susan et al. (2013). „The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the

Reporting of Behavior Change Interventions“. In: *Annals of Behavioral Medicine* 46.1, pp. 81–95. ISSN: 0883-6612, 1532-4796. DOI: 10.1007/s12160-013-9486-6.

Michon, J. (1985). „A critical view of driver behavior models: What do we know“. In: *Human Behavior and Traffic Safety*. Ed. by L. Evans and R.C. Schwing. Springer, Boston, MA. ISBN: 978-1-4612-9280-7. URL: https://doi.org/10.1007/978-1-4613-2173-6_19.

Miron-Shatz, Talya, Arthur Stone, and Daniel Kahneman (2009). „Memories of yesterday's emotions: Does the valence of experience affect the memory-experience gap?“ In: *Emotion* 9.6, pp. 885–891. ISSN: 1931-1516, 1528-3542. DOI: 10.1037/a0017823.

Molen, Hugo H. van der and Anton M. T. Bötticher (1988). „A hierarchical risk model for traffic participants“. In: *Ergonomics* 31.4, pp. 537–555. ISSN: 0014-0139. DOI: 10.1080/00140138808966698.

Monge Roffarello, Alberto and Luigi De Russis (2019). „The race towards digital wellbeing: Issues and opportunities“. In: *CHI '19: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–14. DOI: 10.1145/3290605.3300616.

Morris, Eric A. and Erick Guerra (2015). „Mood and mode: does how we travel affect how we feel?“ In: *Transportation* 42.1, pp. 25–43. DOI: 10.1007/s11116-014-9521-x.

Moudon, Anne Vernez et al. (2005). „Cycling and the built environment, a US perspective“. In: *Transportation Research Part D: Transport and Environment* 10.3, pp. 245–261. ISSN: 1361-9209. DOI: 10.1016/j.trd.2005.04.001.

Mumford, Stephen and Rani Lill Anjum (2013). *Causation: a very short introduction*. 1. ed. Very short introduction 371. Oxford: Oxford Univ. Press. 128 pp. ISBN: 978-0-19-968443-4. URL: https://www.veryshortintroductions.com/view/10.1093/actrade/9780199684434.001.0001/actrade-9780199684434.

Murphy, Brendan and Andrew Owen (2019). „Implementing Low-Stress Bicycle Routing in National Accessibility Evaluation“. In: *Transportation Research Record* 2673.5, pp. 240–249. ISSN: 0361-1981. DOI: 10.1177/0361198119837179.

Nations, United (2014). *World Urbanization Prospects: The 2014 Revision Highlights*.

Neubauer, Andreas B. et al. (2020). „How was your day? Convergence of aggregated momentary and retrospective end-of-day affect ratings across the adult life span.“ In: *Journal of personality and social psychology* 119.1, p. 185. DOI: 10.1037/pspp0000248.

Norman, Don (2013). *The design of everyday things: Revised and expanded edition*. Basic books. ISBN: 978-0-262-52567-1.

Norman, Donald A. (1993). „Cognition in the head and in the world: An introduction to the special issue on situated action“. In: *Cognitive science* 17.1, pp. 1–6. DOI: 10.1207/s15516709cog1701_1.

Nunes, Francisco (2015). „Designing Self-care Technologies for Everyday Life: A Practice Approach“. In: *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. CHI EA '15. New York, NY, USA: ACM, pp. 215–218. ISBN: 978-1-4503-3146-3. DOI: 10.1145/2702613.2702624.

Nuss, Kayla et al. (2021). „Effects of Motivational Interviewing and Wearable Fitness Trackers on Motivation and Physical Activity: A Systematic Review". In: *American Journal of Health Promotion* 35.2, pp. 226–235. ISSN: 0890-1171. DOI: 10.1177/0890117120939030.

Nussbaum, Ryan et al. (2019). „Systematic Review of Mobile Health Applications in Rehabilitation". In: *Archives of Physical Medicine and Rehabilitation* 100.1, pp. 115–127. ISSN: 0003-9993. DOI: 10.1016/j.apmr.2018.07.439.

Ogilvie, D. (2004). „Promoting walking and cycling as an alternative to using cars: systematic review". In: *BMJ* 329.7469, pp. 763–. ISSN: 0959-8138, 1468-5833. DOI: 10.1136/bmj.38216.714560.55.

Oinas-Kukkonen, Harri and Marja Harjumaa (2008). „A Systematic Framework for Designing and Evaluating Persuasive Systems". In: *Persuasive Technology*. Ed. by Harri Oinas-Kukkonen et al. Lecture Notes in Computer Science 5033. Springer Berlin Heidelberg, pp. 164–176. URL: http://link.springer.com/chapter/10.1007/978-3-540-68504-3_15.

Okugawa, Ryo et al. (2015). „Training system of bicycle pedaling using auditory feedback". In: *ACE '15: Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology*, pp. 1–4. DOI: 10.1145/2832932.2832972.

Pakkanen, Toni et al. (2008). „Perception of Low-amplitude Haptic Stimuli when Biking". In: *Proceedings of the 10th International Conference on Multimodal Interfaces*. ICMI '08. New York, NY, USA: ACM, pp. 281–284. ISBN: 978-1-60558-198-9. DOI: 10.1145/1452392.1452449.

Parkin, John, Tim Ryley, and Tim Jones (2007). „Barriers to cycling: an exploration of quantitative analyses". In: *Cycling and society*. Ed. by Dave Horton, Paul Rosen, and Peter Cox. Routledge, pp. 83–98. ISBN: 978-1-315-57573-5.

Parkin, John, Mark Wardman, and Matthew Page (2007). „Estimation of the determinants of bicycle mode share for the journey to work using census data". In: *Transportation* 35.1, pp. 93–109. ISSN: 0049-4488, 1572-9435. DOI: 10.1007/s11116-007-9137-5.

Patton, Michael Quinn (2005). *Qualitative research*. Wiley Online Library.

Pearson, Lauren et al. (2022). „The potential for bike riding across entire cities: Quantifying spatial variation in interest in bike riding". In: *Journal of Transport & Health* 24, p. 101290. ISSN: 2214-1405. DOI: 10.1016/j.jth.2021.101290.

Piatkowski, Daniel et al. (2015). „Measuring the Impacts of Bike-to-Work Day Events and Identifying Barriers to Increased Commuter Cycling". In: *Journal of Urban Planning and Development* 141.4. ISSN: 0733-9488. DOI: 10.1061/(ASCE)UP.1943-5444.0000239.

Pielot, Martin et al. (2012). „Tacticycle: supporting exploratory bicycle trips". In: *MobileHCI '12: Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services*, pp. 369–378. DOI: 10.1145/2371574.2371631.

Pinder, Charlie et al. (2018). „Digital Behaviour Change Interventions to Break and Form Habits". In: *ACM Trans. Comput.-Hum. Interact.* 25.3, 15:1–15:66. ISSN: 1073-0516. DOI: 10.1145/3196830.

Ponterotto, Joseph G. (2005). „Qualitative research in counseling psychology: A primer on research paradigms and philosophy of science.“ In: *Journal of counseling psychology* 52.2, pp. 126–136. DOI: 10.1037/0022-0167.52.2.126.

Pooley, Colin G. et al. (2013). „Policies for promoting walking and cycling in England: A view from the street“. In: *Transport Policy* 27, pp. 66–72. ISSN: 0967-070X. DOI: 10.1016/j.tranpol.2013.01.003.

Poppinga, Benjamin, Martin Pielot, and Susanne Boll (2009). „Tacticycle: a tactile display for supporting tourists on a bicycle trip“. In: *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*. MobileHCI '09. New York, NY, USA: Association for Computing Machinery, pp. 1–4. ISBN: 978-1-60558-281-8. DOI: 10.1145/1613858.1613911.

Prochaska, James O. (Mar. 11, 2015). „High Impact Digitally Tailored Behavior Change Programs“. URL: https://www.media.mit.edu/videos/wellbeing-2015-11-03-2/.

Prochaska, James O. and Carlo C. Diclemente (1986). „Toward a Comprehensive Model of Change“. In: *Treating Addictive Behaviors*. Ed. by William R. Miller and Nick Heather. Applied Clinical Psychology 13. Springer US, pp. 3–27. ISBN: 978-1-4612-9289-0. URL: https://link.springer.com/chapter/10.1007/978-1-4613-2191-0_1.

Pucher, John and Ralph Buehler (2006). „Why Canadians cycle more than Americans: A comparative analysis of bicycling trends and policies“. In: *Transport Policy* 13.3, pp. 265–279. ISSN: 0967-070X. DOI: 10.1016/j.tranpol.2005.11.001.

— (2008). „Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany“. In: *Transport Reviews* 28.4. Publisher: Routledge, pp. 495–528. ISSN: 0144-1647. DOI: 10.1080/01441640701806612.

Pucher, John, Jennifer Dill, and Susan Handy (2010). „Infrastructure, programs, and policies to increase bicycling: An international review“. In: *Preventive Medicine* 50, Supplement, S106–S125. ISSN: 0091-7435. DOI: 10.1016/j.ypmed.2009.07.028. URL: http://www.sciencedirect.com/science/article/pii/S0091743509004344 (visited on 03/18/2015).

R Core Team (2015). *R: A Language and Environment for Statistical Computing*. ISBN 3-900051-07-0. Vienna, Austria. URL: http://www.R-project.org/.

Reckwitz, Andreas (2002). „Toward a Theory of Social Practices A Development in Culturalist Theorizing“. In: *European Journal of Social Theory* 5.2, pp. 243–263. ISSN: 1368-4310, 1461-7137. DOI: 10.1177/13684310222225432.

Reddy, Sasank et al. (2010). „Biketastic: Sensing and Mapping for Better Biking“. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '10. New York, NY, USA: ACM, pp. 1817–1820. ISBN: 978-1-60558-929-9. DOI: 10.1145/1753326.1753598.

Reutter, OJEB (2004). „The 'YOU-move. nrw'campaign–New partnerships for youth-oriented and environmentally friendly mobility management Oscar Reutter“. In: *World Transport Policy & Practice* 10.4. Publisher: Citeseer, pp. 15–21. ISSN: 1352-7614. URL: https://trid.trb.org/view/754083.

Rhodes, Ryan E. and Gert-Jan de Bruijn (2013). „How big is the physical activity intention–behaviour gap? A meta-analysis using the action control framework". In: *British Journal of Health Psychology* 18.2, pp. 296–309. ISSN: 2044-8287. DOI: 10.1111/bjhp.12032.

Rittenbruch, Markus et al. (2020). „An Exploratory Physical Computing Toolkit for Rapid Exploration and Co-Design of On-Bicycle Notification Interfaces". In: *Proceedings of the 2020 ACM Designing Interactive Systems Conference*. DIS '20. New York, NY, USA: Association for Computing Machinery, pp. 873–884. ISBN: 978-1-4503-6974-9. DOI: 10.1145/3357236.3395534.

Rogers, Yvonne (2012). „HCI Theory: Classical, Modern, and Contemporary". In: *Synthesis Lectures on Human-Centered Informatics* 5.2. Publisher: Morgan & Claypool Publishers, pp. 1–129. ISSN: 1946-7680. DOI: 10.2200/S00418ED1V01Y201205HCI014.

Rogers, Yvonne et al. (2007). „Why it's worth the hassle: the value of in-situ studies when designing Ubicomp". In: *Proceedings of the 9th international conference on Ubiquitous computing*. UbiComp '07. Berlin, Heidelberg: Springer-Verlag, pp. 336–353. ISBN: 978-3-540-74852-6. DOI: 10.5555/1771592.1771612.

Rose, Geoff and Heidi Marfurt (2007). „Travel behaviour change impacts of a major ride to work day event". In: *Transportation Research Part A: Policy and Practice* 41.4, pp. 351–364. ISSN: 0965-8564. DOI: 10.1016/j.tra.2006.10.001.

Rowland, Duncan et al. (2009). „Ubikequitous computing: designing interactive experiences for cyclists". In: *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*. MobileHCI '09. New York, NY, USA: Association for Computing Machinery, pp. 1–11. ISBN: 978-1-60558-281-8. DOI: 10.1145/1613858.1613886.

Ryan, Richard M. and Edward L. Deci (2000). „Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions". In: *Contemporary Educational Psychology* 25.1, pp. 54–67. ISSN: 0361-476X. DOI: 10.1006/ceps.1999.1020.

Ryerson, Megan S. et al. (2021). „Evaluating cyclist biometrics to develop urban transportation safety metrics". In: *Accident Analysis & Prevention* 159, p. 106287. ISSN: 0001-4575. DOI: 10.1016/j.aap.2021.106287.

Schatzki, Theodore R. (1996). *Social Practices: A Wittgensteinian Approach to Human Activity and the Social*. Cambridge University Press. 261 pp. ISBN: 0-521-56022-5.

Scholten, Mark R., Saskia M. Kelders, and Julia EWC van Gemert-Pijnen (2017). „A Scoped Review of the Potential for Supportive Virtual Coaches as Adjuncts to Self-guided Web-Based Interventions". In: *Persuasive Technology: Development and Implementation of Personalized Technologies to Change Attitudes and Behaviors. PERSUASIVE 2017*. International Conference on Persuasive Technology. Springer, pp. 43–54. DOI: 10.1007/978-3-319-55134-0_4.

Schön, Donald A. (1983). *The reflective practitioner: how professionals think in action*. New York: Basic Books. 374 pp. ISBN: 978-0-465-06874-6.

Schwartz, Tobias et al. (2013). „Uncovering Practices of Making Energy Consumption Accountable: A Phenomenological Inquiry". In: *ACM Trans. Comput.-Hum. Interact.* 20.2, 12:1–12:30. ISSN: 1073-0516. DOI: 10.1145/2463579.2463583.

Seale, Clive (1999). „Quality in Qualitative Research“. In: *Qualitative Inquiry* 5.4, pp. 465–478. DOI: 10.1177/107780049900500402.

Semanjski, Ivana et al. (2016). „Policy 2.0 Platform for Mobile Sensing and Incentivized Targeted Shifts in Mobility Behavior“. In: *Sensors* 16.7. Number: 7 Publisher: Multidisciplinary Digital Publishing Institute, p. 1035. DOI: 10.3390/s16071035.

Shapiro, Samuel Sanford and Martin B. Wilk (1965). „An analysis of variance test for normality (complete samples)“. In: *Biometrika* 52.3, pp. 591–611. DOI: 10.2307/2333709.

Sharma, Arundathi M. et al. (2016). „Towards a maximally-robust self-balancing bicycle without reaction-moment gyroscopes or reaction wheels“. In: *Proceedings, Bicycle and Motorcycle Dynamics 2016*. Symposium on the Dynamics and Control of Single Track Vehicles. Milwaukee, Wisconsin, USA.

Shove, Elizabeth (2010). „Beyond the ABC: climate change policy and theories of social change“. In: *Environment and Planning A* 42.6, 1273 –1285. DOI: 10.1068/a42282.

Shove, Elizabeth, Mika Pantzar, and Matt Watson (2012). *The Dynamics of Social Practice: Everyday Life and how it Changes*. Sage Publications, Ltd. 210 pp. ISBN: 978-0-85702-042-0.

Siewiorek, D. P. (2012). „Virtual coaches in health care“. In: *IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN 2012)*. IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN 2012). ISSN: 2325-6664, pp. 1–1. DOI: 10.1109/DSNW.2012.6264659.

Silberman, M. Six et al. (2014). „Next steps for sustainable HCI“. In: *Interactions* 21.5, pp. 66–69. ISSN: 1072-5520. DOI: 10.1145/2651820.

Skinner, David and Paul Rosen (2016). „Hell Is Other Cyclists: Rethinking Transport and Identity“. In: *Cycling and Society*. Ed. by Dave Horton, Paul Rosen, and Peter Cox. Ashgate Publishing Limited, pp. 99–112. ISBN: 978-0-7546-4844-4.

Slovák, Petr, Christopher Frauenberger, and Geraldine Fitzpatrick (2017). „Reflective Practicum: A Framework of Sensitising Concepts to Design for Transformative Reflection“. In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. CHI ’17. New York, NY, USA: Association for Computing Machinery, pp. 2696–2707. ISBN: 978-1-4503-4655-9. DOI: 10.1145/3025453.3025516.

Slovic, Paul et al. (2005). „Affect, risk, and decision making“. In: *Health Psychology* 24.4, S35–S40. ISSN: 1930-7810. DOI: 10.1037/0278-6133.24.4.S35.

Sniehotta, Falko F., Justin Presseau, and Vera Araújo-Soares (2014). „Time to retire the theory of planned behaviour“. In: *Health Psychology Review* 8.1, pp. 1–7. ISSN: 1743-7199. DOI: 10.1080/17437199.2013.869710.

Soon, Chun Siong et al. (2008). „Unconscious determinants of free decisions in the human brain“. In: *Nature Neuroscience* 11.5, pp. 543–545. ISSN: 1097-6256. DOI: 10.1038/nn.2112.

Sörös, Gábor, Florian Daiber, and Tomer Weller (2013). „Cyclo: A Personal Bike Coach Through the Glass“. In: *SIGGRAPH Asia 2013 Symposium on Mobile Graphics and Interactive Applications*. SA ’13. New York, NY, USA: ACM, 99:1–99:4. ISBN: 978-1-4503-2633-9. DOI: 10.1145/2543651.2543660.

Spotswood, Fiona et al. (2015). „Analysing cycling as a social practice: An empirical grounding for behaviour change". In: *Transportation Research Part F: Traffic Psychology and Behaviour* 29, pp. 22–33. ISSN: 1369-8478. DOI: 10.1016/j.trf.2014.12.001.

Squire, Larry R. (2004). „Memory systems of the brain: A brief history and current perspective". In: *Neurobiology of Learning and Memory*. Multiple Memory Systems 82.3, pp. 171–177. ISSN: 1074-7427. DOI: 10.1016/j.nlm.2004.06.005.

Steg, Linda (2005). „Car use: lust and must. Instrumental, symbolic and affective motives for car use". In: *Transportation Research Part A: Policy and Practice*. Positive Utility of Travel 39.2, pp. 147–162. ISSN: 0965-8564. DOI: 10.1016/j.tra.2004.07.001.

Stelling-Konczak, Agnieszka, Marjan Hagenzieker, and Bert Wee (2015). „Traffic Sounds and Cycling Safety: The Use of Electronic Devices by Cyclists and the Quietness of Hybrid and Electric Cars". In: *Transport Reviews* 35. DOI: 10.1080/01441647.2015.1017750.

Steltenpohl, Haska and Anders Bouwer (2013). „Vibrobelt: tactile navigation support for cyclists". In: *IUI '13: Proceedings of the 2013 international conference on Intelligent user interfaces*. IUI '13, pp. 417–426. DOI: 10.1145/2449396.2449450.

Stinson, Monique A. and Chandra R. Bhat (2003). „An Analysis of Commuter Bicyclist Route Choice Using Stated Preference Survey". In: *Transportation Research Board*. Transportation Research Board. Washington, DC.

— (2004). „Frequency of Bicycle Commuting: Internet-Based Survey Analysis". In: *Transportation Research Record* 1878.1. Publisher: SAGE Publications Inc, pp. 122–130. ISSN: 0361-1981. DOI: 10.3141/1878-15.

— (2005). „A Comparison of the Route Preferences of Experienced and Inexperienced Bicycle Commuters". In: *TRB 84th Annual Meeting Compendium of Papers*.

Stone, Jeff and Joel Cooper (2001). „A Self-Standards Model of Cognitive Dissonance". In: *Journal of Experimental Social Psychology* 37.3, pp. 228–243. ISSN: 0022-1031. DOI: 10.1006/jesp.2000.1446.

Strengers, Yolande (2014). „Smart energy in everyday life: Are you designing for resource man?" In: *Interactions* 21.4, pp. 24–31. DOI: 10.1145/2621931.

Taylor, Dean and Hani Mahmassani (1996). „Analysis of stated preferences for intermodal bicycle-transit interfaces". In: *Transportation Research Record* 1556.1. Publisher: SAGE Publications Sage CA: Los Angeles, CA, pp. 86–95. DOI: 10.1177/0361198196155600111.

Telfer, B. et al. (2006). „Encouraging cycling through a pilot cycling proficiency training program among adults in central Sydney". In: *Journal of Science and Medicine in Sport* 9.1, pp. 151–156. ISSN: 1440-2440. DOI: 10.1016/j.jsams.2005.06.001.

Tertoolen, Gerard, Dik van Kreveld, and Ben Verstraten (1998). „Psychological resistance against attempts to reduce private car use". In: *Transportation Research Part A: Policy and Practice* 32.3, pp. 171–181. ISSN: 0965-8564. DOI: 10.1016/S0965-8564(97)00006-2.

Thaler, Richard H. and Cass R. Sunstein (2009). *Nudge: improving decisions about health, wealth and happiness*. New internat. ed. London: Penguin. 305 pp. ISBN: 978-0-14-104001-1.

Theeboom, Tim, Bianca Beersma, and Annelies E. M. van Vianen (2014). „Does coaching work? A meta-analysis on the effects of coaching on individual level outcomes in an organizational context". In: *The Journal of Positive Psychology* 9.1, pp. 1–18. ISSN: 1743-9760. DOI: 10.1080/17439760.2013.837499.

Tornivuori, Anna et al. (2020). „A systematic review on randomized controlled trials: Coaching elements of digital services to support chronically ill adolescents during transition of care". In: *Journal of Advanced Nursing* 76.6, pp. 1293–1306. ISSN: 1365-2648. DOI: 10.1111/jan.14323.

Tsukada, Koji and Michiaki Yasumura (2004). „ActiveBelt: Belt-type Wearable Tactile Display for Directional Navigation". In: *UbiComp 2004: Ubiquitous Computing*. Springer, pp. 384–399. DOI: 10.1007/978-3-540-30119-6_23.

Verplanken, Bas and Henk Aarts (1999). „Habit, Attitude, and Planned Behaviour: Is Habit an Empty Construct or an Interesting Case of Goal-directed Automaticity?" In: *European Review of Social Psychology* 10.1, pp. 101–134. ISSN: 1046-3283. DOI: 10.1080/14792779943000035.

Verplanken, Bas, Henk Aarts, and Ad van Knippenberg (1997). „Habit, information acquisition, and the process of making travel mode choices". In: *European Journal of Social Psychology* 27, pp. 539–560.

Waard, Dick de et al. (2017). „Visual map and instruction-based bicycle navigation: a comparison of effects on behaviour". In: *Ergonomics* 60.9, pp. 1283–1296. DOI: 10.1080/00140139.2017.1282628.

Wagner, Ben, Till Winkler, and Soheil Human (2021). „Bias in Geographic Information Systems: The Case of Google Maps". In: Hawaii International Conference on System Sciences (HICSS54). Hawaii, United States/USA. DOI: 10.24251/HICSS.2021.103.

Warde, Alan (2005). „Consumption and Theories of Practice". In: *Journal of Consumer Culture* 5.2. Publisher: SAGE Publications, pp. 131–153. ISSN: 1469-5405. DOI: 10.1177/1469540505053090.

Wardman, Mark, Miles Tight, and Matthew Page (2007). „Factors influencing the propensity to cycle to work". In: *Transportation Research Part A: Policy and Practice* 41.4, pp. 339–350. ISSN: 0965-8564. DOI: 10.1016/j.tra.2006.09.011.

Watson, Matt (2012). „How theories of practice can inform transition to a decarbonised transport system". In: *Journal of Transport Geography*. Special Section on Theoretical Perspectives on Climate Change Mitigation in Transport 24, pp. 488–496. ISSN: 0966-6923. DOI: 10.1016/j.jtrangeo.2012.04.002.

Wernbacher, Thomas et al. (2015). „Traces: A pervasive app for changing behavioural patterns". In: *Proceedings of The 9th European Conference on Game Based Learning*. Academic Conferences International Limited, p. 589.

Wierda, M. and K. A. Brookhuis (1991). „Analysis of cycling skill: A cognitive approach". In: *Applied Cognitive Psychology* 5.2, pp. 113–122. ISSN: 1099-0720. DOI: 10.1002/acp.2350050205.

Wintersberger, Philipp (2020). „Automated Driving: Towards Trustworthy and Safe Human-Machine Cooperation". PhD thesis.

Wittgenstein, Ludwig (1968). *Philosophical investigations*. Oxford: Basil Blackwell. 250 pp. ISBN: 978-0-631-11900-5.

Wobbrock, Jacob O. and Julie A. Kientz (2016). „Research contributions in human-computer interaction". In: *Interactions* 23.3, pp. 38–44. ISSN: 1072-5520. DOI: 10.1145/2907069.

Wright, Peter and John McCarthy (2008). „Empathy and experience in HCI". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '08. New York, NY, USA: Association for Computing Machinery, pp. 637–646. ISBN: 978-1-60558-011-1. DOI: 10.1145/1357054.1357156.

Wunsch, Matthias and Geraldine Fitzpatrick (2021). „Complex Contexts and Subtle Actions: Design and Evaluation of a Virtual Coach for Utilitarian Cycling". In: *Human-Computer-Interaction – INTERACT 2021*. Ed. by Carmelo Ardito et al. Cham: Springer International Publishing, pp. 125–146. ISBN: 978-3-030-85607-6. DOI: 10.1007/978-3-030-85607-6_9.

Wunsch, Matthias, Alexandra Millonig, et al. (2016). „Challenged to Bike: Assessing the Potential Impact of Gamified Cycling Initiatives". In: Transportation Research Board (TRB) 95th Annual Meeting 2016. January 10–14, 2016. Washington, DC. URL: https://trid.trb.org/view/1394343.

Wunsch, Matthias, Agnis Stibe, Alexandra Millonig, Stefan Seer, Ryan CC Chin, et al. (2016). „Gamification and Social Dynamics: Insights from a Corporate Cycling Campaign". In: *International Conference on Distributed, Ambient, and Pervasive Interactions*. Springer, pp. 494–503. DOI: 10.1007/978-3-319-39862-4_45.

Wunsch, Matthias, Agnis Stibe, Alexandra Millonig, Stefan Seer, Chengzhen Dai, et al. (2015). „What Makes You Bike? Exploring Persuasive Strategies to Encourage Low-Energy Mobility". In: *Persuasive Technology*. Ed. by Thomas MacTavish and Santosh Basapur. Lecture Notes in Computer Science. Springer International Publishing, pp. 53–64. DOI: 10.1007/978-3-319-20306-5_5.

Wynes, Seth and Kimberly A. Nicholas (2017). „The climate mitigation gap: education and government recommendations miss the most effective individual actions". In: *Environmental Research Letters* 12.7, p. 074024. ISSN: 1748-9326. DOI: 10.1088/1748-9326/aa7541.

Zacharias, John (2005). „Non-motorized transportation in four Shanghai districts". In: *International Planning Studies* 10.3, pp. 323–340. ISSN: 1356-3475, 1469-9265. DOI: 10.1080/13563470500378911.

Zahran, Sammy et al. (2008). „Cycling and walking: Explaining the spatial distribution of healthy modes of transportation in the United States". In: *Transportation Research Part D: Transport and Environment* 13.7, pp. 462–470. ISSN: 13619209. DOI: 10.1016/j.trd.2008.08.001.

Appendix: Abbreviations and Definitions

Abbreviations

e.g. ... "exempli gratia", Latin for "for example"

GUI ... graphical user interface

HCI ... Human Computer Interaction(s)

i.e. ... "id est", Latin for that is

ICT ... Information and Communication Technology

VUI ... voice user interface

Definitions of Key Terms

adoption

Adopting a practice is to incorporate it into ones routine activities. This is similar to habit formation in terms of the decisions being cognitively automated and regularly repeated. However, the term adoption should carry the meaning of being an intently process that is in line with motivation, desires or wishes of an individual. This is in contrast with habits that can form unconsciously and might pose eventually negative consequences.

capability

Used within this these in the context of cycling. "capability is initially constrained by biological characteristics of the driver, such as information processing capacity and speed, reaction time, physical reach, motor coordination and perhaps flexibility and strength. ... However, this competence is not necessarily what is delivered at any moment of time because capability is vulnerable to a host of human factor variables. These include factors of attitude, motivation, effort, fatigue, drowsiness, time-of-day, drugs, distraction, emotion and stress. Any of these can detract from driver competence to yield a somewhat lower level of capability." (Fuller 2005)

competencies

"knowledge and skills arising out of training and experience. Such knowledge includes formal elements such as rules of the road, procedural knowledge defining what to do under what circumstances (conditional rules) and a representation of the dynamics of road and traffic scenarios which enable prediction of how those scenarios will develop... Skills include control skills associated with basic vehicle control as well as handling skills in challenging circumstances (such as a skid). Together these biological characteristics and acquired characteristics through training and experience determine the upper limit of competence of the driver." (Fuller 2005)

information and communication technology (ICT)

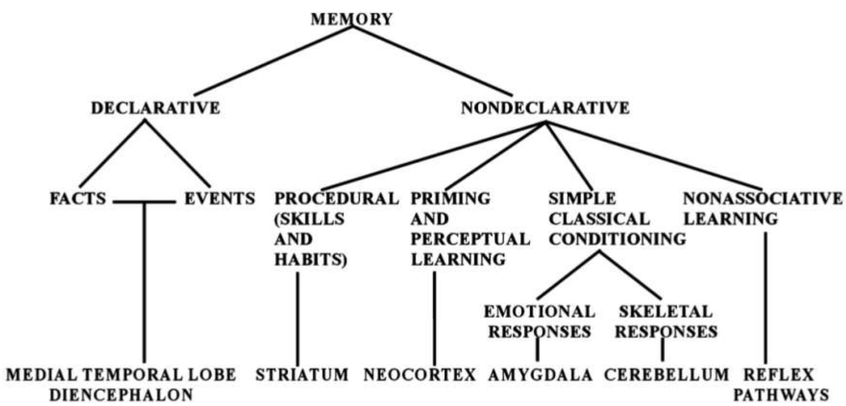
Definition of ICT from the Cambridge Business English Dictionary: "The use of computers and other electronic equipment and systems to collect, store, use, and send data electronically."

meaning

A shared understanding that includes "symbolic meanings, ideas and aspirations" (Shove, Pantzar, and Watson 2012). Meaning is created through it's use (Wittgenstein 1968; Schatzki 1996).

memory systems

I used the taxonomy of long-term memory systems from Squire (2004) shown in the figure below. This taxonomy includes a mapping to the particularly relevant brain structures for each memory system.



motivation

"To be motivated means to be moved to do something." (Ryan and Deci 2000)

(extrinsic) motivation

Doing an activity to attain a distinct outcome (Ryan and Deci 2000).

(intrinsic) motivation

Doing an activity “for its inherent satisfaction rather than for some separable consequence” (Ryan and Deci 2000).

utilitarian cycling

Using the bicycle to derive utility such as getting to a desired location or transporting goods. It is typically integrated into ones everyday routines, such as commuting to work, transporting one’s children, or running errands. It differs from cycling as as leisure time activity, e.g. a ride together with family on a weekend as a way to explore an area without sportive ambitions. It also differs from sportive cycling, e.g. road cycling or mountain-biking, which emphasises physical exercise, training and competition. Seen from a social practice perspectives, similar elements can form these activities, such as the bicycle, gear, roads, and skills used to ride. However, the meanings between these types of cycling differ substantially. This also reflects back on the design of technology, which may emphasize quite different aspects e.g. between sportive and utilitarian cycling.

Appendix to Chapter 4

This appendix includes further details on Case Study I (Frequent Biking Challenge), Case Study II (Virtual Bike Tutorial), and Case Study III (Bike Buddy Program).

Questionnaires

The questionnaires used in all three case studies.

Perceived Safety Questionnaire

Think of yourself biking for your usual trips. How do you rate the likelihood of these statements?

Scale: very unlikely (1) to very likely (6)

- Cars will drive too close to me.
- I'll be cut off by cars while turning.
- I'll be hit by a car because a driver is not paying attention.
- Cars will drive too fast near me. I'll get doored.
- Car drivers will be aggressive towards me.
- I'll make a mistake and hurt others or myself.
- I'll fall off the bike because I can't keep the balance.
- I'll hit a pedestrian who gets in my way without paying attention.
- Other bikers will drive too fast near me.
- Potholes (or circumventing potholes) will cause an accident.
- I'll have an accident in the dark as I am not visible enough.
- Add your Comments:

Perceived Self-Efficacy Questionnaire

Question: Again, think of yourself biking for your usual trips. How do you rate the following statements (from very unlikely to very likely): **Scale:** very unlikely (1) to very likely (6)

- Wearing a helmet increases my safety.
- Biking with others increases my safety.
- Biking is safe if bike lanes are available on the entire route.
- Biking in off-peak hours increases my safety.
- Riding on a bike with lights, signals or reflectors on increases my safety.
- Having a big red bell on my bike increases my safety.
- Regular biking will increase my safety.
- Add your Comments:

Open Question Follow-Up Questionnaire

This questionnaire was sent to participants of case study I nine months after the initial study.

List of open questions:

- Before I started biking, my main reasons not to bike were:
- Why I started biking:
- Biking in my hometown was/is...
- Why I bike:
- What I like about biking:
- Typical situations for me to bike are:
- Typical situations where I do not bike are:
- Do you have any safety concerns with biking? If so, how do you deal with it?
- Do your friends or your family members bike? If not, what keeps them from biking?
- Do you try to encourage others to bike? How?
- Please tell us, what else we should know about biking from your experience?
- Shall we inform you about our outcomes? (Yes / No)

Interview Guidelines

Interview guideline for case study I and II

Goals:

- verify, if safety concerns are as important as we assume;
- find out, how the interventions worked,
- explore the effects of the interventions

- Mobility patterns
  - What are your usual mobility patterns, which modes do you use?
  - How do you feel about biking?
  - Which barriers are there which hinder you from biking (more)? (ranking)
  - Do you think that there are many people biking? Why (not)? Would it be better if more people were biking?
  - Why did you participate in this experiment? Would you have done it, if it hadn't been for science?
- Operational framework
  - How did you feel during the experimental phase? What were your impressions?
  - How did the operational framework work for you (communication, paperwork etc.)?
- Did you notice any change in your behavior or your perception of mobility or biking?
  - In general
  - Related to the trip diary
  - Related to the intervention
- Specific for case study I (Frequent Biking Challenge):
  - Which effects did the daily email reminders have?
  - Did you feel motivated by the badges?
  - Did you like the notifications? Why (not)?
  - Which part did you like best?
  - What did you think about the leaderboard and the ranking?
- Specific for Case Study II (Virtual Bike Tutorial):

  - What do you remember from the videos?
  - What were the goals in your opinion?
  - What did you learn?

- Impact assessment

  - What is the potential impact of such measures in your opinion?
  - For whom would it work and why?
  - Would you do in a different way and how?

Design of the Virtual Bike Tutorial

Training part within the Virtual Bike Tutorial

Training 1

Scene:

- **Anticipate:**

  - I'm biking on a busy street. Cars could pass by too close to me

- **React:**

  - Take my space on the road.
  - Keep enough distance to sidewalk.
  - Ride with a speed that is comfortable for me.

Training 2

Scene:

- **Anticipate:**
  - A car door could open (danger of “getting doored”).
- **React:**
  - Keep enough distance to parking cars (more than 3ft). or
  - Slow down so that I could stop even if a door opens in front of me.

Training 3

Scene:

- **Anticipate:**
  - Pedestrians could overlook me and get in me way.
- **React:**
  - Yield to pedestrians.
  - Slow down.

Training 4

Scene:

- **Anticipate:**
  - The bike lane crosses the sidewalk. Pedestrians could overlook me.
- **React:**
  - Be prepared for pedestrians crossing your way.
  - Keep distance where pedestrians could appear.
  - Slow down.

Appendix to Chapter 5

The following table contains the data on motivators per group presented in Figure 5.2. The survey question was: “What motivated you while you were participating in Bike to Work?” Participants could select the items that they agreed with (dichotomus scale). p-values are the results of Chi-Squared test for independency between all three groups.

Group Commute by bike	**Occasional bikers** never to (almost) weekly	**Regular bikers** several times a week	**Daily bikers** (almost) daily	**p-value**
Health benefits **)	69.9%	59.5%	45.9%	<0.001
Team spirit *)	58.3%	45.7%	41.0%	0.011
Environmental protection	57.3%	54.3%	53.8%	0.828
Individual statistics	38.8%	32.8%	30.8%	0.340
Prizes	31.1%	33.6%	38.7%	0.328
Biked distance	31.1%	39.7%	35.3%	0.414
Biking enthusiasm of colleagues	16.5%	20.7%	15.4%	0.446
Motivate others to bike **)	14.6%	42.2%	44.0%	<0.001

*) p-value <0.05

**) p-value <0.01

Appendix to Chapter 6

Included below is the document that got submitted to M.I.T.s Committee on the Use of Humans as Experimental Subjects (COUHES) for the ethical review of Case Study VII (Virtual Cycling Coach).

	Massachusetts Institute of Technology Committee on the Use of Humans as Experimental Subjects	**Application #** (assigned by COUHES)	
		Date	

APPLICATION FOR APPROVAL TO USE HUMANS AS EXPERIMENTAL SUBJECTS (STANDARD FORM)

Please answer every question. Positive answers should be amplified with details. You must mark N/A where the question does not pertain to your application. Any incomplete application will be rejected and returned for completion. ***A completed CHECKLIST FOR STANDARD APPLICATION FORM must accompany this application.***

I. BASIC INFORMATION

1. Title of Study	
Virtual Bike Coach	
2. Principal Investigator	
Name: Kent Larson	Building and Room #:E15-368
Title: Principal Research Scientist	Email: kll@mit.edu
Department: Media Lab, Changing Places	Phone: 617-253-8799

3. Key Personnel

All *key personnel*[1] **including the PI** *must be listed below, with a brief statement of qualifications and study role(s).*
Important Note: *all key personnel are required to complete Human Subject training before work begins on the project.*

Investigators and other personnel [and institution(s)] include email address:	*Qualifications: Describe briefly*	*Study role(s):*	*Check box if person will be obtaining consent*	*Check box if current human subject training*
Agnis Stibe agnis@mit.edu	Postdoc, Persuasive Urban Systems	Project Manager, Study Lead	☒	☒
			☐	☐

[1] MIT key personnel include all individuals who contribute in a substantive way to the execution and monitoring of the study at or on behalf of MIT or affiliated institutions. Typically, these individuals have doctoral or other professional degrees, although other individuals may be included. In particular, investigators and staff involved in obtaining informed consent are considered key personnel.

			☐	☐
			☐	☐
			☐	☐

4. Collaborating Institutions. *If you are collaborating with another institution(s) then you must obtain approval from that institution's institutional review board, and forward copies of the approval to COUHES).*

5. Location of Research. *If at MIT please indicate where on campus. If you plan to use the facilities of the Clinical Research Center you will need to obtain approval of the MIT Catalyst Clinical Research Center.*

Greater Boston area / MIT Media Lab, Changing Places Research Group (E15-368)

6. Funding. *If the research is funded by an outside sponsor, please enclose one copy of the research proposal with your application. A draft of the research proposal is acceptable.* ***Do not leave this section blank. If your project is not funded check No Funding.***

A. Sponsored Project Funding:

☐ Current Proposal Proposal # ____________________
Sponsor ________________________
Title ________________________

☐ Current Award Account # ____________________
Sponsor ________________________
Title ________________________

B. Institutional Funding:

☐ Gift
☐ Departmental Resources
☐ Other (explain) ____
☒ No Funding

7. Statement of Financial Interest

Does the principal investigator or any key personnel involved in the study have any financial interest in the research?

☐ Yes ☒ No

If yes then attach a **Supplement for Disclosure of Financial Interest** for each individual with an interest. *This supplement, together with detailed guidance on this subject and definitions of the highlighted terms, is available on the COUHES website at: [INSERT LINK].*

8. Human Subjects Training. *All study personnel* ***MUST*** *take and pass a training course on human subjects research. MIT has a web-based course that can be accessed from the main menu of the COUHES web site. COUHES may accept proof of training from some other institutions. List the names of all study personnel and indicate if they have taken a human subjects training course.*

Kent Larson and Agnis Stibe have completed the human subjects training	

course.	
9. Anticipated Dates of Research	
Start Date: 06/20/2016	Completion Date: 08/31/2016

II. STUDY INFORMATION

1. Purpose of Study. *Please provide a concise statement of the background, nature and reasons for the proposed study. Use non-technical language that can be understood by non-scientist members of COUHES.*
This study explores how the development of urban cycling competences can be supported with technology. The study focuses on fostering reflection in action and providing deliberate practice to users. Thereby, novel and scalable competence development technologies are developed and scientifically evaluated.
2. Study Protocol. *For* ***biomedical, engineering and related research****, please provide an outline of the actual experiments to be performed. Where applicable, provide a detailed description of the experimental devices or procedures to be used, detailed information on the exact dosages of drugs or chemicals to be used, total quantity of blood samples to be used, and descriptions of special diets.* *For applications in the* ***social sciences, management and other non-biomedical disciplines*** *please provide a detailed description of your proposed study. Where applicable, include copies of any questionnaires or standardized tests you plan to incorporate into your study. If your study involves interviews please submit an outline indicating the types of questions you will include.* *You should provide sufficient information for effective review by non-scientist members of COUHES. Define all abbreviations and use simple words. Unless justification is provided for additional length, this part of the application must not exceed 5 pages.* *Attaching sections of a grant application is not an acceptable substitute for a description of your study as requested here.*
The study will research the use of software for developing a user's urban cycling competences. The involved human subjects participate in coaching sessions, where they are asked to ride a bike in various environments, such as areas with no traffic, on bike lanes and in mixed traffic. They get instant feedback from a "virtual bike coach", a software that runs on a smartphone or tablet attached to the bike which outputs audio messages. These messages are selected by the study investigator based on the current task and given environment. The messages and feedback from the virtual bike coach is based on existing curricula for urban cycling education. These are meant to foster reflection in action of users and to improve their behavior if necessary. Besides hearing the audio messages, users can also talk back to the device and a voice recognition and processing is simulated in order to create a conversational setting. Human subjects participating in this study will typically participate in two of these coaching sessions, depending on how much time they are willing to invest. The sessions will take place within the Greater Boston area and in daylight. The exact place and time will be set with each

participant on an individual basis. The study will mainly use qualitative methods such as open question interviews in order to gather insights on the learning process during and after these sessions. Besides that, quantitative data such as the currently used modes of transportation, regularly travelled distances e.g. for commuting, household status, residential area and the like are collected (see questionnaire attached).
3. Drugs and Devices. *If the study involves the administration of an investigational drug that is not approved by the Food and Drug Administration (FDA) for the use outlined in the protocol, then the principal investigator (or sponsor) must obtain an Investigational New Drug (IND) number from the FDA. If the study involves the use of an approved drug in an unapproved way the investigator (or sponsor) must submit an application for an IND number. Please attach a copy of the IND approval (new drug), or application (new use.).* *If the study involves the use of an investigational medical device and COUHES determines the device poses significant risk to human subjects, the investigator (or sponsor) must obtain an Investigational Device and Equipment (IDE) number from the FDA.*
Will drugs or biological agents requiring an IND be used? YES ☐ **NO** ☒ *If yes, please provide details:* **Will an investigational medical device be used? YES** ☐ **NO** ☒ *If yes, please provide details:*
4. Radiation *If the study uses radiation or radioactive materials it may also have to be approved by the Committee on Radiation Exposure to Human Subjects (COREHS). COUHES will determine if you need COREHS approval.*
Will radiation or radioactive materials be used? YES ☐ **NO** ☒ *If yes, please provide details:* **Will any type of lasers be used YES** ☐ **NO** ☒ *If yes, please provide details:*
5. Diets
Will special diets be used? YES ☐ **NO** ☒ *If yes, please provide details*

III. HUMAN SUBJECTS

1. Subjects (*that will be consented for this study*)	
A. Maximum number: 50	**B. Age(s):** 18+

C. Inclusion/exclusion criteria

i. **What are the criteria for inclusion or exclusion?** Being able to ride a bike and having a basic knowledge on traffic rules (e.g. owning a driving licence).

ii. **Are any inclusion or exclusion criteria based on age, gender, or race/ethnic origin?** *If so, please explain and justify*
No.

D. Please explain the inclusion of any vulnerable population (e.g. children, cognitively impaired persons, non-English speakers, MIT students), and why that population is being studied.
N/A

2. Subject recruitment *Identification and recruitment of subjects must be ethically and legally acceptable and free of coercion. Describe below what methods will be used to identify and recruit subjects.*
Subjects will be recruited through mailing lists and social networks.
Please attach a copy of any advertisements/ notices and letters to potential subjects
3. Subject compensation *Payment must be reasonable in relation to the time and trouble associated with participating in the study. It cannot constitute an undue inducement to participate.*
Describe all plans to pay subjects in cash or other form of payment (i.e. gift certificate): No cash or other form of payments will be provided.   **Will subjects be reimbursed for travel and expenses?** No.
4. Potential risks. *A risk is a potential harm that a reasonable person would consider important in deciding whether to participate in research. Risks can be categorized as physical, psychological, sociological, economic and legal, and include pain, stress, invasion of privacy, embarrassment or exposure of sensitive or confidential data. All potential risks and discomforts must be minimized to the greatest extent possible by using e.g., appropriate monitoring, safety devices and withdrawal of a subject if there is evidence of a specific adverse event.*
What are the risks / discomforts associated with each intervention or procedure in the study? This study requires participants to ride a bike instead of using other modes of transport. This poses a different type of risk/danger to the subject than that of using a motor vehicle, public transport or walking. Furthermore, the intervention design is meant to be mentally engaging with the riding situation. However, a potential risk is that users might get distracted by the tested technology.   **What procedures will be in place to prevent / minimize potential risks or discomfort?** The study investigator will meet the participant, reiterate the purpose oft he study and introduce

the used – mainly a smartphone app prototype – to the participant. Furthermore, the investigator will control the output of the app while the participants use it ("Wizard of Oz" technique). While riding within traffic, the study investigator will ride along (typically behind) the participant. The study investigator will always be present during the rides, personally ensuring for a maximum of safety for the participant.

5. Potential benefits

What potential benefits may subjects receive from participating in the study?
Participants may benefit by learning how to ride within a city in a safer, more comfortable way.

What potential benefits can society expect from the study?
The change in transportation modes from driving to biking has environmental, health, and urban congestion improvements across the board.

6. Data collection, storage, and confidentiality

How will data be collected?
Data will be collected via self-reporting on an online system.

Is there audio or videotaping? YES ☒ NO ☐ ***Explain the procedures you plan to follow.***
Interviews with the study participants will be audio recorded for later analysis. Furthermore, short video clips will be recorded of the participants while riding for evaluation of their learning progress during their study participation.

Will data be associated with personal identifiers or will it be coded?

Personal identifiers ☒ Coded ☐ ***Explain the procedures you plan to follow.***
As this study is of a mainly qualitative nature, each user can be identified personally by the investigators.

Where will the data be stored and how will it be secured?
Data will be stored locally on the MIT Media Lab investigators PCs. These are password protected and not accessible by other persons than the involved researchers.

What will happen to the data when the study is completed?
Data allowing for personal identification will be deleted after the completion of data Researchers will seek out additional consent if the data is to be used for purposes that were not previously comprehensively described.

Can data acquired in the study affect a subject's relationship with other individuals (e.g. employee-supervisor, patient — physician, student-teacher, family relationships)?
The data acquired in the study will not affect in any way a subject's relationships with others.

7. Deception *Investigators must not exclude information from a subject that a reasonable person would want to know in deciding whether to participate in a study.*

Will information about the research purpose and design be withheld from subjects?
YES ☐ NO ☒

If YES, explain and justify.
8. Adverse effects. *Serious or unexpected adverse reactions or injuries must be reported to COUHES within 48 hours. Other adverse events should be reported within 10 working days.*
What follow-up efforts will be made to detect any harm to subjects, and how will COUHES be kept informed? If any adverse effects are experienced by users, we will ask to be contacted, and will make sure to inform COUHES in a prompt manner. We will help as much as possible when contacted.
9. Informed consent. *Documented informed consent must be obtained from all participants in studies that involve human subjects. You must use the templates available on the COUHES web-site to prepare these forms. Draft informed consent forms must be returned with this application. Under certain **very limited** circumstances COUHES may waive the requirement for informed consent.*
Attach informed consent forms with this application.
10. Health Insurance Portability and Accountability Act ("HIPAA"). *If your study (i) involves individually identifiable health information and (ii) is sponsored by MIT Medical, an MIT Health Plan or another healthcare provider, then you must complete the questions below because HIPAA likely applies to your study. For more information regarding the applicability of HIPAA to human subjects research, please see: [INSERT LINK TO HIPAA GUIDANCE DOCUMENT.]*
Do you plan to obtain, use or disclose identifiable health information in connection with your research study? **YES** ☐ **NO** ☒ *If YES, then all participants must complete an Authorization for Release of Protected Health Information Form. Please attach a copy of this draft form. You must use the template available on the COUHES web-site. See: [INSERT LINK].* *Alternatively, COUHES may grant a Waiver of Authorization in certain **very limited** circumstances when use of individually identifiable health information would pose only minimal risk to study participants (among other requirements). For additional information regarding whether your study might qualify for a waiver, please see: [INSERT LINK TO HIPAA GUIDANCE DOCUMENT].* **Are you requesting a Waiver of Authorization?** **YES** ☐ **NO** ☒ *If YES, explain your rationale for concluding that: (i) use of participant health information poses no more than minimal risk; (ii) the research could not be conducted without the waiver and (iii) the research could not be conducted without the information. In addition, please explain your plan for (i) ensuring the participant health information is not improperly used or disclosed either within MIT or to any outside third parties and (ii) destroying identifiers at the earliest possible*

opportunity.

Will the health information you will receive for use in this study be de-identified?
YES ☐ **NO** ☒

If YES, you do not need to obtain a signed Authorization for Release of Protected Health Information Form from study participants. Note, however, that if you receive identifiable participant health information that you plan to convert into de-identified information for use by other researchers, then you must obtain a signed Authorization for Release of Protected Health Information Form from each participant before receiving their identifiable health information for use in your study.

Will you be using or disclosing a limited data set?
YES ☐ **NO** ☒

If YES, and you will only receive participant health information in limited data set form, then you do not need to obtain a signed Authorization for Release of Protected Health Information Form from study participants. You must complete a formal data use agreement with the party from whom you will receive the limited data set information in order for your application to be approved.

If YES, and you will receive identifiable participant health information that you plan to convert into limited data set form for use by other researchers, then you must obtain a signed Authorization for Release of Protected Health Information Form from each participant before receiving their identifiable health information for use in your study. You must complete a formal data use agreement in order for your application to be approved..

IV. INVESTIGATOR'S ASSURANCE

I certify the information provided in this application is complete and correct.

I understand that I have ultimate responsibility for the conduct of the study, the ethical performance of the project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by COUHES

I agree to comply with all MIT policies, as well all federal, state and local laws on the protection of human subjects in research, including:

- **ensuring all study personnel satisfactorily complete human subjects training;**
- **performing the study according to the approved protocol;**
- **implementing no changes in the approved study without COUHES approval;**
- **obtaining informed consent from subjects using only the currently approved**

consent form;

- **protecting identifiable health information, to the extent required by law, in accordance with HIPAA requirements; and**
- **promptly reporting significant or untoward adverse effects.**

Signature of Principal Investigator ________________________________ **Date** ___________

Print Full Name and Title ____

Signature of Department Head ____________________________________ **Date** ___________

Print Full Name and Title ____

The electronic file should be sent as an attachment to an e-mail: jadams@mit.edu . In addition, two hard copies (one with original signatures) should be sent to the COUHES office: Building E25-Room 143B.