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Complex Contexts and Subtle Actions: Design and Evaluation of a Virtual Coach for Utilitarian Cycling

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Abstract. The role of HCI to support cyclists has been researched for many years. However, there has been relatively little work on the interaction with and acting within real-world traffic situations. We collaborated with professional cycling instructors to understand experiences of (novice) cyclists in complex real-world urban traffic situations and existing coaching and teaching strategies. Building on this understanding, we designed a system informed by these strategies: an on-the-bike Virtual Cycling Coach (VCC), a system aware of its user’s actions and context that delivers coaching interventions in appropriate moments. In a qualitative in-the-wild study with 25 participants we evaluated if the VCC – as Wizard-of-Oz prototype – can offer a coaching experience. Our findings show that the VCC enables processes such as reflection and learning comparable to conventional coaching settings. We discuss limitations and implications for similar designs in complex, highly context-dependent realms.

Keywords: Mobile HCI · Virtual coach · Cycling.

1 Introduction

Cycling as a low-emission and space-efficient urban mobility option can contribute to ecologically sustainable development in an urbanizing world. [20, 49] The benefits of utilitarian cycling in urban contexts are also substantial on an individual level. Cycling is often a time efficient mode of transportation and has lower costs than other transportation options. [16] It offers immediate health benefits, lowering the risks of cardiovascular disease, cancer, and other causes of mortality. [7] It even brightens one’s mood. [27, 30] However, these intrinsic benefits only weakly relate to the actual experience of adopting urban cycling for commuting or other personal transportation needs, as making it a routine activity means more hurdles to clear. [37] To exemplify this: In a recent study about cycling, a population of 3.000 persons from 50 U.S. metropolitan areas was surveyed. Therein, 10% had used a bicycle for transportation in the last 30 days, and over 50% of the respondents were categorized as “interested but concerned”, that is: they are physically able to ride, but are uncomfortable with biking on

a major street without or with a bike lane, and neutral to interested in riding more. [11] This gap represents an opportunity for design to meet preferences and reduce existing friction in adopting cycling. While this is most typically tackled by civil engineering and transportation research, previous HCI research has also contributed to supporting cycling through exploring technology for navigation, context awareness and behavior change via different modalities (for example [9, 1, 14]). However, there is little research that considers the interplay between an interactive system, a complex context – such as traffic, street design, other road participants, etc. –, and the actions of a cyclist. Hence, the experience of urban cycling is mostly dependent on and left to the design of the built environment.

We report on a series of studies to create an interactive system capable of providing situated, in-the-moment coaching support for cyclists. This paper is structured in two sections following our research trajectory: In the first section we present our studies on novice cyclists and how they are supported by professional cycling instructors. We explore the coaching strategies used in these settings and the experiences of the cyclists. We also highlight limitations of these programs and the opportunities for a technical system to provide situated support. In the second section, we 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.

2 Related Work

As cyclists have to act within and interact with a complex context, they need to exercise skillful control over their bicycle, while applying knowledge and being exposed to a variety of potentially dangerous situations. [34, 45] 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. [12, 36] Starkly simplified, this can be viewed as the built infrastructure being designed for ease of use, thereby reducing the level of proficiency needed to cycle.

A large theme in HCI research is interactive technology for supporting cyclists through navigational guidance. De Waard et al. [50] compare 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 been studied in detail. [2, 35, 43, 48] The use of projections from the bicycle has been explored for both navigation by projecting a map [9] and to project turn signals on the street [10]. On bicycle navigation has also been studied with the goal of supporting excursions and the exploration of unfamiliar environments by bicycle. [33, 35]

Previous studies do show that the experiential quality of a route plays a role in navigation and people trade maximum directness for lower stress. [8] Route choices can also differ dependent 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. [44] This relation between a navigation support system and the cyclist’s experience of built infrastructure has not been studied so far in HCI research. Context awareness in this area of transportation and mobile HCI has been almost exclusively limited to geolocation data. Providing feedback on action on a bike has been studied in multiple ways: Okugawa [32] explored training systems that provide immediate feedback on the pedalling cadence in sports-oriented cycling. Matviienko et al. [28, 29] compared the effectiveness of visual, auditory or vibrotactile cues to warn children while cycling. There is also research on how such warnings could be realized in real-world settings using vehicular ad-hoc network technologies. [19] 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. [1]

Cycling has also been studied from a behaviour change agenda. In a recent review, Klecha and Gianni [22] outline commonly used approaches: Supporting eco-friendly choices such as cycling is done with information and guidance using journey planning services. [21, 25, 40] Game-like designs are used in “sustainability challenges“, as well as rewards, that usually are virtual points. [6, 14, 51, 55] Social influence and social comparison are used and instantiated e.g. with leader boards [21, 25, 51, 54, 13]. Another approach is self-monitoring, often enabled through graphical, statistical representations of reported or logged mobility behaviour. [6, 14, 40, 51, 55] As these studies focus on choices, none have been concerned with the experience of a mobility practice and how technology could be used to offer in-the-moment support within the complex context often found when cycling in an urban environment.

As for coaching, we understand it broadly ‘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.’ [17] 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. [46] There is the subset of virtual coaching or e-coaching, characterized by using information and communication technologies as 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. [47] Another study on virtual coaching – including ones fully executed by systems through a set of pre-defined questions – did produce comparable outcomes to conventional interpersonal coaching. [15] There are no studies so far that investigated a coaching approach in the domain of utilitarian cycling.

3 Existing Teaching and Coaching Strategies

To inform the design of our technology intervention, we focus on users that are beginning to ride bicycles to fulfil their transportation needs. To gain a better

understanding of the experiences of (novice) cyclists, we worked together with a local bike advocacy group in Vienna, Austria, that offers classes for beginning and for advanced cyclists. Furthermore, we worked with a cycling coach from the same region specialized in supporting his customers to learn cycling for utilitarian purposes.

3.1 Methods

Empathetic participant observation is key for gaining knowledge about the experiences of people in this situation. [53] For this, we 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. We 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, we 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.

Analysis Thematic analysis was used to identify and structure emerging themes regarding the experiences of urban cycling. [4, 3] The collected notes and descriptions were coded, analyzed and structured by a pair of researchers to produce the results described in 3.2. 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 they are similar or different to our data. In reflection on and engaging with the data, we could emphasize with the experiences of urban cyclists we observed in the teaching settings.

3.2 Findings: Existing Support Strategies

To answer, how professional instructors teach and support cyclists we present the course structures, course curricula, strategies for scaffolding of learning experiences, framings, the use of feedback and motivational support, the student’s agency and the role of reflection in the trainings.

Course Structures There are different courses for a beginner and an advanced level. The former prepares the students for recreational cycling in traffic-free areas, the latter prepares them to ride their bikes for everyday trips in an urban environment. The classes consist of ten sessions, held weekly, each lasting for two hours. The number of students per class could go up to 20. As not all of them attend all sessions, some sessions have had only five attendees. In the coaching setting, the coach has only one student for usually three to five sessions, each

lasting for two hours and being typically about one to two weeks apart. While the coach did also offer trainings on a beginner and advanced level, the content was mainly driven by the student's needs.

Training Content The curriculum for the beginner level covers 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 practice 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. Hence, students have to be able to handle their bicycle well enough to participate in the advanced level trainings, 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.

Scaffolded Learning Experiences The training at the beginner level take place in socially and spatially safe spaces. The novice cyclists are provided with an accepting, patient and open-minded social space where students do not have to feel ashamed when they have problems or fail to do certain exercises and “where it is okay, to learn cycling as an adult” [Instructor 1]. These trainings are conducted within recreational areas with no motorized 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 reduces the cognitive capacity for coping with interacting in complex situations (also see [52, 5]).

For the advanced level, the instructors or coach select routes that are appropriate to the current level of competencies of the student(s). The selection of these routes is done very deliberately, to provide the right sort of experience – or teachable moments – to the students. An example is riding within a lane with shared traffic, i.e. together with motorized vehicles and next to parked cars. The loud, heavy and fast-moving vehicles are stress-inducing and typically result in negative emotional responses. We observed that defensively riding cyclists tend 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 – results in a more dangerous situation for her. Coaching can 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 are deliberately used, especially in the coaching sessions. For example, motorized vehicles are 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 is fear, which is a negative emotion commonly 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 is scared. Beyond that, with their own behaviour and attitude towards cycling, the instructors and coach act as a role model. They 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 share their attitude towards cycling in the city, as 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 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 are 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. He was therefore at the time experimenting with providing students with annotated video recordings of their rides for them to analyse and reflect upon later.

Agency We observed that the setup as a group with an instructor riding up-front reduced the agency of individual students. They were mostly focused on following and imitating the rider in front of them, being less aware and less considerate than when riding on their own. In contrast, in the coaching sessions, the student typically rode ahead with the coach riding behind them, creating 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 emphasises cyclists 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 [39] 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”.

Limitations Both the class and coaching settings struggle with providing feedback in the moment while being in traffic. 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 mostly occurred for individuals and not the entire group. Hence, even though the group allows more students to practice at the same time, the lack of intermediate feedback on an individual’s teachable moments likely results in a less effective learning setup.

The one-on-one coaching setting offered more tailored and adaptive training to students. This however could not scale to the needs of the students in the classes. There, the needs and problems could vary substantially between students. E.g. a set of students did have a drivers licence and were therefore familiar with traffic rules and signs, but struggled with handling the bike and fear from motorized vehicles. Within the same class, other students were handling the bicycle proficiently but failed to follow the traffic signs and general traffic rules.

Another limitation regarding scale was the actual spatial context of the sessions. The coach tried to ride in areas that his student would be riding in the future as well. Organizationally this was not possible for the classes. Therefore, the students could never practice riding where they live 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 is taking it already for the second time and does really enjoy it but does not feel confident enough yet to ride in the area she is living in.

4 In-Action-Support for Challenging Experiences: The Virtual Cycling Coach

Based on the studies presented above, 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 [41, 24]: “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 the limitations found in the existing teaching approaches: 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.

4.1 Design

Monitoring User’s Actions and Context-Awareness The design of a virtual coach was chosen to enable individualized, 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 this research project. To avoid limiting the design by that, we used a Wizard-of-Oz-prototype, where a present researcher would control the VCC. On the bicycle, a web-application running on a regular smartphone acted as a software client. The present researcher would trigger the VCC using the GUI of a web-based controller. A web-backend enabled the communication between controller and client. Using such a Wizard-of-Oz-prototype allowed us to focus on the effect of the VCC on the study participants and gain insights into the feasibility of such a design.

Interaction Design For the output, we chose an audio-based voice user interface (VUI). Its ubiquitous use in navigation systems and prior studies with cyclists repeatedly reported this as being the preferred interaction mode. [23, 26, 28, 38] The VUI of the prototype used pre-recorded audio messages and did not offer an option to freely communicate with the cyclist.

Coaching Interventions of the Virtual Cycling Coach The VCC should be offering support similar to the advanced level training described above, i.e. persons that can balance, steer and control a bicycle and knew 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. The interventions – examples are shown in Table 1 – are informed by the insights reported from the

exploratory studies presented above. Additionally, guidelines for cyclists from Boston (MA), educational material from bike advocacy groups¹ and textbooks used for cycling education in primary schools in Austria have been used to design the individual interventions.

Coaching Strategy The coaching interventions target the “manoeuvring level” of cycling [52], that includes e.g. decisions are made about the course and tactics in traffic, selection of appropriate speeds in a specific situation or interaction 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. [42] A session could start with riding on a quiet street and looking back or giving hand signals. Later on, more complex contexts can be combined with more difficult exercises, e.g. doing a left turn on a busy street intersection. An excerpt of the the curriculum developed for the VCC is shown in Table 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. [39] For example, while riding in traffic the VCC would prompt awareness and anticipation, but also 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.

4.2 Methods for Evaluation

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. The evaluation was conducted in two subsequent rounds, in Greater Boston, MA, US and Vienna, Austria. Both cities do see a steady increase in bicycle ridership.² Both provide dedicated cycling infrastructure. However, this is mostly retrofitted to existing streets resulting in complex negotiations with other road users, particularly at intersections.

The sessions using the VCC lasted between 20 to 45 minutes. Each session began with an introduction to the idea of the Virtual Cycling Coach and a

¹ <http://www.bikeleague.org/ridesmart>, last accessed at Feb 2021

² <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 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 motorized 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 on own awareness	When entering more crowded context, e.g. entering an area with motorized 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."
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 (e.g. to overtaking or unpredictably moving vehicles)	Participant has been riding too close to a pedestrian, parked vehicle or a physical obstacle. Simulated input: object detection and sonar/radar/LIDAR based 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. Participant riding with sufficient space to parked vehicle (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."

short semi-structured interview to assess the participants 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. E.g., a novice cyclist would have been given all basic exercises and doing those in a traffic-free or low-traffic area, whereas an experienced cyclist would have started to ride within denser traffic right from the beginning.

Participants were recorded and asked to think aloud to collect data on thoughts that occur in-the-moment. Observational material was collected as well, 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 the researcher.

First Evaluation Round: Cambridge, MA, United States Fifteen adults were recruited in the Greater Boston area (MA, United States) 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 20 to early 60. The evaluation study took place in Cambridge 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.³ The present researcher followed the participants on a bike controlling the VCC and partially instructed participants where to go. Furthermore, he used traffic related stops (e.g. at red lights, stop signs, etc.) to gather *in situ* feedback from participants about their experience using the VCC. 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 talking with the researcher(s). The 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 the researcher’s bike to record the participant with more distance from behind. While starting the video a live timestcode 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 have been 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.

³ 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 obvious safety reasons and participants did not find it distracting. However, at times they could not hear messages from the VCC.

Second Evaluation Round: Vienna, Austria The main reason to conduct this second evaluation round was to examine if an observer effect has been introduced due to the researcher riding behind participants. To reduce such a possible observer effect, the VCC client smartphone was put in a casing, mounted on a bicycle’s handlebar. The casing – shown in Figure 1 – included a second smartphone that would live-stream a video to the researcher showing the current location and environment. This eliminated the need to follow the study participants as the VCC could now be controlled remotely by the researcher who stayed at the meeting point, using a laptop to use the VCC controller. 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 to record the sessions.

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 from between 20 and 40 years. The evaluation study took place in Vienna over a period of eight weeks. The researcher instructed participants to ride for about 20 minutes without any more specific information regarding the route.



Fig. 1. The 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 loudspeaker for outputs of the audio interface, and a 360° camera on top for recording the session.

Sample The overall study sample 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 did primarily use her car. As for their experience with urban cycling, one participant had none, 13 participants had some 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 shown in Figure (2). The latter offered detailed, contextualized information on the experiences of the study participants which were annotated along with the transcripts. The data was partially transcribed and summed up by three researchers. A thematic analysis was used to provide a detailed account within the data. [4] 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. We aimed at finding “repeated patterns of meaning” [4] across the data set. Those identified themes and presented in the results lean towards the semantic end on the spectrum from semantic to latent themes.

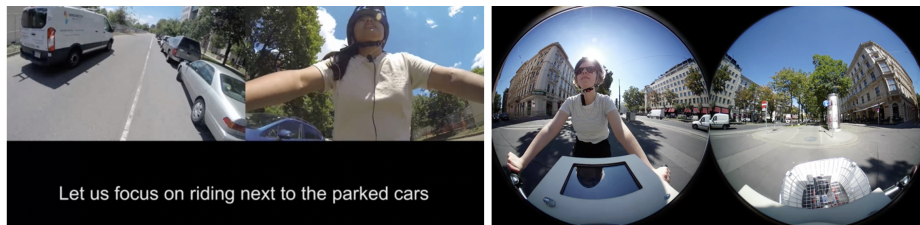


Fig. 2. Combined video and log data used for analysis of the rides using the Virtual Cycling Coach (VCC) from the first evaluation round (left). 360° video from second evaluation round (right).

4.3 Findings from Qualitative Evaluation of the Virtual Cycling Coach

Using the Virtual Cycling Coach was overall appreciated by the study participants. They found the idea interesting and saw value in the in the moment feedback. 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 practicing opportunity out of an occurring experience or teachable moment, in-the-moment guidance was a prominent feature – allowing users 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 practice right turns. (pause) The sequence is: Look back, signal, turn if possible.”

This framing was reported back by the study participants, as they all viewed using the VCC as a learning or coaching experience.

Participants were often prompted by the VCC to repeat exercises and those could take place in several different locations. E.g., the VCC would prompt 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 3.2.

Furthermore, the VCC was designed to scaffold the learning experience for its users, e.g. by doing certain exercises in safe or less complex environments. Scaffolding was important for the challenge to be at the right level in relation to the competences of the participant, that is being not too easy but also not too hard. [42] A typical session therefore started in areas with little or no traffic from motorized vehicles, as shown in Figure 3. 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 — follow-up interview — all names are changed for anonymity]



Fig. 3. Start of a session with the VCC in an area without motorized 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 that was how to interact with motorized 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 1-meter (3 foot) safety distance 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 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 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 While it is difficult for the cycling instructors and the coach to give in the moment feedback as well as to prompt reflection-in-action, technology makes it possible to deploy that. 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 as illustrated in the excerpt above. Our analysis did not reveal differences between the two study waves that would be based on 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 1 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 finding 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 is riding in an area with other cyclists and pedestrians and no motorized traffic. The VCC says “Let us practice some basics.” The participant is riding at a low speed while thinking aloud: “*Make sure you don't get in the way of other bikers.*” Then, the VCC says “Watching out is crucial for cycling. Now try to ride in a straight line while looking behind you from time to time.” The exercise is meant to deliberately practice looking back without losing control or balance. The participant is trying to ride in a straight line while looking back, which at first he does not achieve. While doing so, he is 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 enter the area and pass close by. The participant continues to think 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 did improve 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 Competences 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 to uncover differences between them and less experienced cyclists. From those experienced cyclists, two did mention 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]

5 Discussion

We used a prototype that simulates understanding of context, actions of users and is able to provide relevant *in situ* interventions in-the-wild. Our findings show that the tight coupling between real experiences of users and the interventions by the virtual coach enabled meaningful learning and reflection.

Technologically, there is currently no system capable of understanding traffic contexts, human actions and human experiences. Especially not one that could be fitted and used on a bicycle. Resorting to safe spaces like a design studio [39] or even a cycling simulator would be a way to study a system in a more controlled and safe environment. However, this would not generate comparably realistic experiences [29], while the Wizard-of-Oz prototype did sufficiently simulate the system and allowed us to study the interplay between the real contexts, the user's in-the-moment real actions and experiences. As there are fast advancements in the field of autonomous systems [18], especially regarding systems capability to understand contexts, technology will eventually be suitable to be used on a bicycle eliminating the need for the Wizard-of-Oz prototype. Our insights allow to inform the design of such systems already today.

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. Future work using voice user interfaces on bicycles should therefore offer a way for users to easily change the playback volume. Failures of the system, such as providing an inappropriate message, were seen as flaws of the prototypical setup by participants within the evaluation study. 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 unexperienced cyclists for potentially slower routes if they offer a more pleasant experience. [8, 44]

A future approach might be to always offer a virtual coach. This would allow to extend existing learning contexts, 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.

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. 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. [24, 31] Beyond the domain of health our work can also inform research in care for elderly, social-emotional-learning, or on-the-job coaching.

6 Conclusion

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

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