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Cyclists' Use of Technology While on Their Bike

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ABSTRACT

Cycling continues to grow in popularity, both as a means to commute and for exercise. While there is a plethora of research studying technology use in vehicular travel, cycling remains a relatively understudied area—especially within HCI. We conducted an ethnography, adopting an ethnomethodological lens, to study cyclists as they use their bicycles for routine purposes. Through the use of a handlebar-mounted 360-degree action video camera, we conducted our study longitudinally with participants over a number of weeks. Our analysis explicates our participants accountable use of different electronic technologies while on the go and in this paper we present four fragments of their use of different technologies as exemplars from our corpus. Our paper offers insights into the use of technology on bicycles, including how cyclists select moments of opportunity to use technology for different purposes. We conclude by offering design implications for the design of interactive technologies for cyclists.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; *Field studies*; *Empirical studies in ubiquitous and mobile computing*.

KEYWORDS

cycling, mobile interaction, smart watch, smartphone, bike computer, earphones, ethnomethodology, video ethnography

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1 INTRODUCTION

Cycling is an increasingly popular way of travelling, whether it be for commuting, leisure, due to an interest in sustainable futures, or as a result of the COVID-19 pandemic [45]. Cities and towns around the world—large and small—have also introduced new temporary or permanent bicycle spaces, including dedicated segregated cycle lanes to provide safer spaces for cyclists [8]. There is an interest within HCI on the design and use of technologies for cycling; however, while there have been some novel prototypes developed, their adoption by manufacturers of commercial products seems somewhat more limited [60]. Presently, much technology developed for cyclists seems to take cues from designs for cars [60], with approaches often treating the handlebar in much the same fashion as that of a dashboard in a vehicle. In contrast to imagining new technologies and their impact on cycling, in this paper, we turn to examine the 'state of play' of cycling: and crucially want to take stock of different forms of digital technology being used, and to understand exactly how cyclists use it while *on the go*. The need for this sort of work is evidenced by, for example, one study in the Netherlands that showed 4.4% of cyclists cycling through a city centre location used their mobile phone [15].

Broadly, HCI features many studies focusing on the use of mobile technologies while people are actively moving, ranging from notification management with smartphones [18], smart glasses-type devices while walking through the city [41], to technologies designed to enhance collocated interaction [48]. However, as noted by others (e.g., [28]), there is a relatively small, but growing, body of literature on HCI and cycling[1], and more broadly, outdoor activities [27]. In work that has considered this domain, there has been an emphasis on developing novel mechanisms to encourage or ensure the safety of cyclists [16, 43, 69], taking the form of a range of multi- or unimodal interaction technologies using handlebar-mounted devices, helmet-embedded devices, or even augmenting the bicycle itself [42, 72]. This work is to be welcomed, given we know in many places people have been shown to use their mobile phone and other digital technologies, while cycling [15, 33], which has been shown to lead to an increased crash risk [2]. Despite the proposals for novel approaches to reducing the risks of using a device in motion—which we hope and assume does not need any defence—we ask just how are existing commercially-available personal computing technologies used *in situ*, contrasting to others that have used lab studies or researcher-defined outdoor routes and tasks [28]. A recent article [60] provides a good review of technology-focused contributions (e.g., the use of gestural input when cycling); our contribution is distinct to these: through an ethnographic study, and following on from HCI's *turn to the social* [64], this paper seeks

[1] In searching the ACM Digital Library, we found six articles where "HCI" and "cycling" occur in Author Keywords, for example.

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to explicate cyclists' interactional 'work' of cycling and using some form of personal technology at the same time.

Due to the COVID-19 pandemic and the need to follow social/physical distancing guidance, we conducted our study of cyclists using 360-degree cameras mounted to their bicycles, with participants completing journeys without any supervision from researchers. We recruited cyclists and asked them to complete routine journeys, except for recording them to allow us to 'observe' their practices through our analysis. Using our audio-video data, we adopt an ethnomethodological orientation [20] to unpack the accountable actions of cyclists during their journey. In this paper, we present four fragments of our corpus, which are used to *exhibit* how our participants made use of technology while on their bikes.

We first introduce and situate our work among existing literature in HCI and, more broadly, ethnographies of people completing journeys. We then describe our methodological and analytic orientation, which adopts the lens of ethnomethodology, before presenting the findings from our study in a series of fragments of data. Our four fragments show how cyclists can use smartphones, smartwatches, bike-mounted computers, and earphones while cycling. Cyclists in our study typically accomplished this by making preparatory actions before using their device, using their device for a few seconds, and then returning to their previous positioning. Finally, we reflect and synthesise our findings to consider how cyclists self-select their moments of device use and use the handlebar's zonality, and how transitions between different zones are crucial for successfully using technology on a bike. We offer these insights as implications for the design of future technologies.

2 BACKGROUND

Firstly, we combine and synthesise literature focusing on the design of technology for mobility within HCI before considering ethnographic studies of mobility from across disciplines. While there is some work focused on cycling, here we have adopted a more broad approach to including other forms of mobility and technology to provide a more comprehensive literature review.

2.1 Designing technology for outdoors and mobility

Devices designed for cyclists often aid or provide input mechanisms for riders, with research examining how to design such tools in unobtrusive ways so that cyclists can use them with ease, such as work by Claes et al. [9], which took the form of augmenting a cycle route environment by adding input devices along the route for cyclists to use with their feet.Other work has adopted bike or wearer-mounted approaches to enable functionality such as gesture-recognition-based signalling, which allows cyclists to improve their visibility to other road users [14]. This has even consisted of handlebar-based detection of micro gestures (i.e., fingers or subtle hand movements) [65, 73], allowing cyclists to keep their hands in a relatively fixed position. In one notable study, Hochleitner et al., while investigating how to support smartphone interaction on bicycles without requiring the cyclist to stop, conducted an enactment study and later a controlled outdoor study [29]. Participants in the study cycled along a pre-planned track, comparing their use of wristband interactions, handlebar buttons and touchscreens to play a game, with handlebar buttons being the most preferred by participants [29]. As in this case, much of the work has been accomplished through researchers conducting observational or simulated studies and then crafting technology in response to observed practices.

A recurrent pattern in research on mobility and the outdoors is an orientation to how those navigating make use of landmarks for navigation. Indeed, while much research has focused on temperate climates in urban centres [34], in studying navigation by hikers in a forest, Sarjakoski et al. identified that landmarks are still used as critical points in navigation [59]. Focusing on cycling, Pielot et al. observed tourists navigating on bikes around an island, including how they made and corrected mistakes [49]. They developed a bike-mounted smartphone to guide and support cyclists' safe navigation, with the smartphone displaying landmarks as points of interest—and the cyclist's current distance to them—to attempt to provide efficient navigation [49]. Other approaches adopted in the literature include Holland et al.'s audio-based approach to enabling cyclists to navigate without using their hands or gaze, arguing that cycling "demand[s] a high level of attention [thus audio will allow people] to engage with [other] people and real-world tasks, and to avoid physical dangers" [30].

Turning from outdoor navigation to literature that considers sport and exercise, perhaps unsurprisingly, an underlying theme that emerges is how we can augment exercise activities with technology that is easy to use, and, crucially, involves minimal mental or physical activity. As expanded upon by Helms et al., while outdoors, people adopt the "flexible notion of *away* [...helping us to...] create alternative modes of engaging with technology" [27], or to echo Turkle, we never really *disconnect* [67]. However, as well as some connection to our social lives, technologies may also be designed to support our outdoor lifestyle and encourage greater physical exertion, including adopting gamified aspects, such as work by Zhao et al. [75] in which the authors developed a bike-mounted light projection game for cyclists, encouraging them to add playful effects to cycling in unobtrusive ways [75]. Such work highlights the complex relationship of technology as it is interweaved and used during other activities.

As well as approaching specific activities and sports, literature in HCI has also examined the design and use of wearable technologies for 'everyday life' situations. The ubiquity of wearable technologies means they are relevant to specific activities, including cycling (e.g., many smartwatches have become increasingly targeted towards sporting and exercise tracking activities since the sector developed). Wearables are often studied from a 'positivist' standpoint of how they can provide information and alerts to wearers in subtle and informative ways compared to other technologies such as smartphones (which are often accused of being disruptive [50]). This interest in wearable technologies stems from what is regarded as an 'encumbrance' of interacting with portable technologies, e.g., the challenge of using a smartphone as the user holds it in one hand and uses their other hand to complete a task on the device [44]. An example of this encumbrance is made by Bergstrom-Lehtovirta et al., who highlight that people reduce their preferred walking speed to ensure a stable technological interaction [6]. Such a finding can be used to justify efforts to enable more 'harmonious' use of technology while on the move.

Wearables could be seen as potentially offering the option to enable 'invisible' communication and computation. However, social norms might prohibit the use of many technologies due to their use breaching 'etiquette'. Profita et al. identified that wrists and forearms are socially acceptable locations for technology to be used while people are conversing with another person, which ties into the fact that many wearable technologies take the form of smartwatches [55]. However, Roumen et al. investigated the viability and use of wearable interactive rings to provide minimalist notifications to participants [58]. They found that vibration is the most reliable way to notify users, independently of the level of physical activity [58]—given many devices rely on vibration, including smartwatches, this design choice seems to be the favourite choice of device manufacturers.

Putting this into practice for cyclists, the augmentation of helmets has been shown to be viable for communicating with others around a cyclist [71], or even to provide tactile feedback to the wearer, alerting them to dangers and hazards on their journey, including other vehicles [69]. Response to visual alerts from such devices is influenced both by location and other factors such as activity and occlusion of the person [24]. Kosmalla et al. used similar insights, drawing upon vibration, sound, and visual cues to support navigation during climbing activities, although found that for climbing, sound was the preferred notification mode for climbers [37]. Synthesising this literature, there seems to be a complex picture forming, insomuch that for a person undertaking a physical activity—be it climbing, walking or cycling—they will more readily respond to the needs of their activity than device notifications, irrespective of the type of device or notification they use.

2.2 Studies of *mobility*

Studies of people's *interactional work* [12] has become a widespread practice within HCI and CSCW [61], stemming from HCI's 'turn-to-the-wild'[2] [5, 32], the importance of which was exemplified by Suchman's fundamental work in *Plans and Situated Actions* [64]. This *turn* demonstrated the need to study people and the social organisation of activities being completed rather than abstracting them from research findings with more experimental designs. As argued by Rooksby [57], this does not preclude laboratory or pre-planned studies but rather establishes a requirement for researchers to appreciate and adopt holistic approaches to study design that take stock of much more than just the 'coalface' of using a system [57]. This represents an *ethos* to adopt in study design, if you will, rather than any prescribed methodology. However, the methodology often turned to in HCI and CSCW is that of *ethnography*—perhaps stemming from Bannon et al.'s work on deriving system requirements through an ethnographic approach [4].

Therefore, we turn to ethnographic and qualitative studies of technology use *in motion.* The growing ubiquity of mobile technologies has led to widespread interest in their use, from studies of sedentary settings [53] to while people are active. Such studies have considered multiple modes of transport, ranging from Laurier et al.'s study of families and acquaintances travelling together in cars [38] through to Pizza et al.'s study on the use of smartwatches during everyday life [51]. Travelling in groups—or as Laurier et al. says, "as a together" [38]—has generated significant interest as people interact and co-construct place-making. Research has shown how this is as true for cyclists on leisure rides together [1, 17] as it is for car users [38]. Technology can play a pivotal role in outdoor experiences and mobility more broadly, with Ferreira et al. remarking how "[b]ike touring revolves around a community sharing experiences" on social media [17]. Through these studies, people have been shown to coordinate their joint activities to help make sense of their space and journey as part of a joint activity.

As well as maintaining awareness of each other (when in groups), cyclists have also been shown to maintain significant awareness of their own safety, working to ensure their stability through "timing [and] spacing" [70]. However, de Waard et al. identified how the lane position of cyclists is significantly more likely to vary while they are using a mobile phone, with holding a conversation while cycling leading to a decreased observation of objects along a cycle route [15]. This suggests that although cyclists may work to maintain awareness, they may fail. Moreover, body poses can be especially intriguing while actively exercising. With skiing, for example, Hasegawa et al. used body pose to guide skiers on their centre of gravity, instructing them on how to perfect their pose [25]. Even with driving, there have been attempts to predict or detect 'ideal' moments in which technology such as voice-activated features could be used [36, 62], based on numerous different factors. We did not find such a similar discussion for cyclists, although we suspect there is a strong case for adopting similar approaches to understand their body pose. Our observational study will offer such preliminary insight.

Tuncer et al. conducted an ethnographic study of e-scooter users, revealing how e-scooter users navigate through urban environments and attend to various exigencies throughout their journey as a result of other people or the environment [66]. Likewise, Lloyd conducted an ethnography of cyclists in New Zealand, revealing the intricacies of how cyclists navigate through urban environments, orienting to incidents such as 'near dooring' and so on, while cyclists work to maintain their safety [40]. It is through adopting an ethnomethodological orientation to data collection and analysis that this 'interactional work' through which people—while on the go —navigate and traverse different environments has been revealed in literature. This orientation helps to elucidate the 'inner workings' of such activities and allows the ethnographer to reveal how specific actions by those under study are occasioned and accomplished with routine mundanity.

3 APPROACH

We now describe our approach to data collection and analysis. Our study was approved by Swansea University's College of Science Research Ethics Committee and also underwent an appropriate risk assessment due to the COVID-19 pandemic.

We adopted an ethnomethodological perspective [20], as has been established within HCI to explicate the social organisation of technology use (e.g. [7, 52]). Ethnomethodology focuses the researcher's attention on the accountable—i.e., 'observable and reportable'—actions of people rather than adopting any interpretative or statistical approach. Through this lens, we orient to the orderly *mundane* features of people's actions [39], as experienced

[2] A more accurate term for this would be *turn-to-the-social* or *in the world.*

by 'members' of those settings (i.e., the expectation is that a cyclist or person familiar with cycling will see our findings as 'common sense' based on their experience). We must caution that our intention here is not to establish generalisability of how all cyclists act, but rather to demonstrate the interactional methods through which our participants simultaneously used some form of electronic device while cycling. By extracting this *common sense knowledge*—which is arguably the core subject of sociological study—we can make this understanding available for others [19]. It is the fact that our findings will present a 'machinery of interaction', i.e., our *analysis*, that is understandable to other humans familiar with cycling that establishes the validity of our findings [13, 35].

3.1 Participant recruitment

Seven people participated in the study using a word-of-mouth and mailing list approach to recruitment, including contacts within local cycling groups. All our participants were recruited from the local area to deal with varying COVID-19 restrictions in place during the data collection phase of our study.

We took part in the study ourselves as an exercise to familiarise ourselves with the process of collecting data. While we were already enthusiastic cyclists, taking part in data collection also enabled us to establish a 'vulgar competence' in this research, i.e., it enabled us to establish our "competence in the setting itself, in order to understand life as [participants] themselves comprehend and practice it and to be able to describe in the language of the setting" [56, p. 6].

3.2 Participant on- and off-boarding

We asked our participants to complete a short demographic questionnaire, with information we collected presented in Table 1. Our questionnaire also asked them to provide some basic information about their cycling habits. We had no basis for collecting additional personal information about our participants. We also ran a lightweight debrief with participants to obtain their insight and clarify our observations in our corpus collected from their journeys. In our case, all seven participants identified as men—we had attempted to recruit non-man-identifying participants and accept this as a limitation of our work. Our participants ranged from 23 to 54 years old and identified with a range of cycling habits and ownership. When asked, participants stated how many bicycles they owned or had regular access to (e.g., within the same household); this ranged from 1 (*P6*) to 8 (*P4*) bikes ($M = 3.4$) per participant. Our participants had different forms of technology, from cycling computers with numerous attachments, action cameras, wearables and bike-attached sensors (e.g., helmets for signalling, power meters, and smartwatches). Most participants cycled daily (n=5), with one cycling weekly (*P5*) and one cycling monthly (*P6*). Six participants cycled for exercise, six for commuting purposes, two as part of their work (e.g., for delivery or as a coach), and one took part in racing/competitions.

We met all participants in public spaces or at their homes (but outside) while wearing a mask. We provided each participant with a box containing a 'GoPro MAX 360' camera[3] and corresponding USB-C cable and SD card. This camera is a portable, relatively rugged camera designed to capture 360-degree video. We also included an official cycle mount for the camera to attach the camera to their bicycle. We demonstrated how to attach the mount to a bicycle, to start a recording with the camera, and explained how to access, retrieve and delete data from the camera. All equipment was cleaned before handing it to the participant. We asked all participants to record typical rides—it was their choice which journeys and when they collected data. For safety and ethical reasons, we asked participants never to undertake a ride for the purpose of recording data and that they should never adjust or use the camera while in motion. We also stressed the importance of only doing whatever they 'normally' do: there was no obligation to use any technology or do anything specific for the study other than their typical rides. We highlighted how personal safety was more critical for us than the safe return of the equipment. That said, across all seven participants, one participant came off their bicycle while cycling in the rain; this was not caused by any technology use but instead was due to the inclement weather—the cyclist was fine and able to continue their journey shortly after the accident. Another participant unexpectedly destroyed a camera, which detached from their bike while cycling because they used a sticky pad to attach the camera to their bicycle instead of the provided bike mount. In both situations, both participants reported that no harm came to them.

We allowed all participants to collect any data they wanted to keep before handing back the camera to us. We collected cameras from participants after 1–3 weeks, depending on use and when requested by the participant. Participants were reimbursed with a £25 shopping voucher following their completion of the study.

3.3 Analysis

We collected 17 hours and 57 minutes of data from participants. Table 2 presents the overall 'shape' of our corpus, how much footage we captured from them (in terms of hours), how many episodes/sequences of technology we identified, and which technology was used by the participants in the footage captured. At moments participants successively used more than one technology (e.g., adjusting earphones and then their phone; we have recorded these separately, although our sum of the number of moments combines these as one moment). Participants provided between 1 hour and 6 minutes (*P6*) and 3 hours 49 minutes (*P3*) of data. Although our participants did mention other technologies they owned (e.g., smart bike helmets), we did not witness—or rather—could not observe and thus report upon any use of these. Our study focused on naturalistic data collection only by design thus we had no expectations for minimum/maximum amounts of footage to be captured by participants. We have excluded the use of the camera from our corpus—the camera was part of the study equipment, and thus it can be seen not to form part of the 'naturalistic' focus of our study on our cyclists' typical technology use.

We undertook three phases of analysis with our corpus of data, conducting a preliminary cataloguing exercise before substantively reviewing and then critically and carefully analysing moments of interest to construct our findings [26, 35]. We watched through and catalogued each clip we collected, recording timestamps and moments where we saw some form of technology use, as well as the

[3] https://gopro.com/en/es/shop/cameras/max/CHDHZ-202-master.html

Table 1: Background information about our participants

	Age	Gender	Amateur (1) to Professional (5)	Use a bicycle for… Exercise	Commuting	Leisure	Work	Races	Num. bikes	Freq. rides
P1	23	Man	3	✓	✓	✓			2	Daily
P2	27	Man	2	✓	✓	✓			2	Daily
P3	24	Man	4	✓	✓	✓			5	Daily
P4	20	Man	4	✓	✓	✓	✓		8	Daily
P5	47	Man	2	✓	✓	✓	✓	✓	4	Weekly
P6	28	Man	2	✓					1	Monthly
P7	54	Man	3		✓				2	Daily

Table 2: Overview of data collected from participants. Some moments may feature more than one technology used, as a participant completes one action immediately after another; we have treated these as one 'moment' in the *sum* (∑) column.

	Length of footage	Num. moments of technology used in corpus Computer	Earphones	Smartwatch	Smartphone	∑
P1	2 hrs 41 mins	7	7	8	2	20
P2	2 hrs 3 mins	0	11	12	21	42
P3	3 hrs 49 mins	0	0	7	0	7
P4	2 hrs 42 mins	2	0	2	2	6
P5	1 hr 51 mins	8	0	0	0	8
P6	1 hr 6 mins	0	0	0	4	4
P7	3 hrs 46 mins	0	16	21	0	37

actions of the cyclist at the time and their location (e.g., cycling on the road). Clips were watched through initially after the participant returned the camera to us. We later watched these clips again, discussing moments with participants during the debriefing session to help develop our understanding. By iteratively performing this process after each participant, we established data saturation [23].

During our cataloguing process, we adopted a broad and encompassing nature to the moments we logged, capturing where we saw definitive glances at a device or touching of a device, although we were cautious not to record mere glances down where we could not be sure this was at the technology as opposed to the road. We recorded this catalogue in tabular form and successively edited this catalogue to standardise terminology (e.g., ensuring we consistently referred to devices by the same name)—this enabled the later stratification presented in Table 2. Our intention here was not to adopt *a priori* categorisations of data, but rather to allow these to emerge through our analysis. We did not count all technology 'interactions' as distinct moments, e.g., in cases where we saw reported actions with the same technology within close succession (e.g., two glances at a watch in quick succession were treated as one action as it is impossible to infer the reasoning for a second glance).

We then performed a substantive review to extract 'fragments' of interest composed of different exemplars of device use by our participants. Through this second stage, we were able to hone in on the core elements of our findings. Our findings section below is organised in response to this review's outcomes. In our case, we became particularly interested in the actions of cyclists as they use their technology—not necessarily what was being accomplished with the technology, but what was also being done before, during, and after the technology was used. Through this review, we particularly focused on the physical actions of cyclists (e.g., did they have to move their hands or shift their gaze, etc.). We adopted the approach to viewing the moments leading up to, during, and after device use based on its identified value in literature [35, 53]. While this demarcation may appear to be the adoption of a rigid framework, it is instead, in fact, the absence of such a framework and an ambition to comprehensively understand how device use is *embedded* within—or, perhaps, used 'during'—the activity of cycling as an ongoing routine accomplishment. In other words, the purpose is to see how device use unfolds from 'start' to 'end'—recording what participants did at these moments allows us to make sense of participants' actions from an abstract level.

Finally, we identified fragments that exhibit various methodological accomplishments that enabled us to unpack and present the embedded practice of using technology while cycling. We present four of these fragments in the next section of this paper. While convention with papers presenting work that has adopted an ethnomethodological orientation often involves the adoption of some formal transcription method (e.g., [3]), here we have opted to present 'thick descriptions' [22] that reveal the interactional naturally accountable methods of our participants [11] as there is little spoken interaction during technology use in our corpus. We do not present these fragments as representatives of all technology use by all cyclists or indeed our participants, they are to be treated as exemplars of the sequences that we captured in our study. As stated above, our goal is not to present a view of how all cyclists act, but rather an in-depth examination of the practice of cycling. However, we have occasionally provided numerical indices at various points (including above) but we hasten to stress that this is to provide the reader with insight into the shape of our corpus rather than as a metric upon which to base any quantitative assumptions.

We selected these fragments though for their ability to 'vividly exhibit' [4] the methodological actions we identified of more than one participant—each were typical (within expected variation) of actions by the same cyclist of other cyclists as found in our corpus. We identified the technologies used within our corpus and selected fragments which we felt were exemplars of the methodological accomplishments identified.

Throughout our analysis, and in this paper, we have adopted a stance of avoiding judgement on participants' safety, legality, or 'sensibility'. It is not our intention here to offer insights into whether participants behaved legally or safely while on their bikes, but purely to extract insights to generate novel insights for developing technologies for on-the-go interaction. Although we note, for clarity and to ease readers' concerns, it was not against the law to use a mobile device while cycling on the road at the time of this study. However, there have been calls to introduce such a law in some jurisdictions since data collection was completed [47].

4 FINDINGS

Firstly, we present an 'idealised' case where our participants used a commercially-available bike-attached computer, before moving towards increasingly intricate sequences involving the use of wearables, and then the use of smartphones. In the below four fragments, we have worked to ensure the anonymity of participants by avoiding their faces in imagery, or if not possible, significantly blurring it along with other identifiable features.

4.1 Using a bike-attached computer

In the first case, we consider instances where our participants use a bicycle-mounted computer. We had three participants who used a bicycle computer on at least some of their journeys (as multiple participants had multiple bikes and only had a computer on some of them). Of the three participants with a bike computer, each used their bike computer while in motion occasionally. During the debrief, three participants independently stated they had configured their bike computer for their particular interests and priorities, although they added that they changed the display out of curiosity, for example, while at traffic lights or to compare themselves to their past performance. Cycling, of course, requires cyclists to maintain an awareness of their surroundings. We will present a fragment demonstrating how cyclists take momentary glances at their bike computers for information. Firstly, we offer a description of what we observe before unpacking the implications of this sequence.

In Figure 1, *P1*'s bike computer is mounted on the handlebars centrally and in front of the bicycle. After turning the bike computer on, the device sits in a 'ready' state (step 1), showing multiple statistics with 0 as a value. As well as this computer, the cyclist also has a power meter attached to their bicycle, which measures the torque the cyclist applies to the pedals. This information is fed directly into the computer. It means that as the cyclist begins to pedal, the computer immediately detects motion and begins recording information about the ride, first displaying a large confirmation of 'ride started' (step 2), before returning to the statistics display (step 3)—this time with non-zero values. Approximately four minutes into the ride, the participant changes the display (step 4), altering the information shown to view different statistics. To do this, they press a button on the computer to cycle through several displays. They pause on the screen in step 4 of Figure 1, and then press the same button a few more times to return to the original screen by pressing the button a few more times (step 5) before continuing their journey (step 6). Following this momentary use, the cyclist continues their journey in the same fashion without touching their computer for some time.

We now want to consider the pertinent elements of this sequence. First, while we have not yet focused on gaze, consider here that the display is placed in a forward position with large digits central to the line of vision of the cyclist. As the cyclist moves, starting any tracking occurs automatically, displaying an affirmative message and an auditory chime. A cyclist familiar with their computer can assume no need to examine the computer—this audible chime confirms an expected outcome: the computer begins to record data as the cyclist starts pedalling.

The bike computer, as with many similar devices, can be configured with a number of different modes/displays, where the user can choose which and where information is shown on the screen. In this fragment, the cyclist changes the display shown by pressing a button on the top of the device, which is found at the end of the computer nearest to the cyclist. Thus, as we see in the imagery in Figure 1, as the cyclist moves through the different displays on the device, they rest the palm of their hand on the handlebar, extending their index finger to press the button on the computer to move through displays. This subtle gesture—almost easy to miss—is crucial: the cyclist can rest their palm on the handlebar, allowing them to maintain any desired balance and stability enabled by this gesture while still interacting with the computer. As the participant begins changing the computer back to the original display, their gaze is not directed down at the computer but upwards and looking forward. They press the button several times, return their hand to its original position on the 'hood' of the handlebar, and *then* glance at the display to confirm the success of their action. This ability to use the computer *eyes-free* reveals a *predictability* of the cyclist's interaction with the computer; i.e., it can be completed using touch-only, with a minimal post-use gaze to confirm.

While we designed our study to be as unobtrusive as possible, with cyclists having to put next-to-no cycle effort into supporting data capture, we also observed all participants having to attend to the camera, at least initially on their first rides. Often this involved rotating the camera so that it was once again vertical—suggesting participants had not adequately tightened the camera on the bicycle handlebars. In the case previously mentioned, one participant attached the camera to the handlebar using sticky pads—which became unstuck—causing the camera to fall and both lenses to be significantly scratched. While we saw all participants adjust their camera mid-ride, we did not see any of our cyclists with bike computers change these devices throughout their use; but then none of our cyclists had, as we ascertained, started using these computers recently.

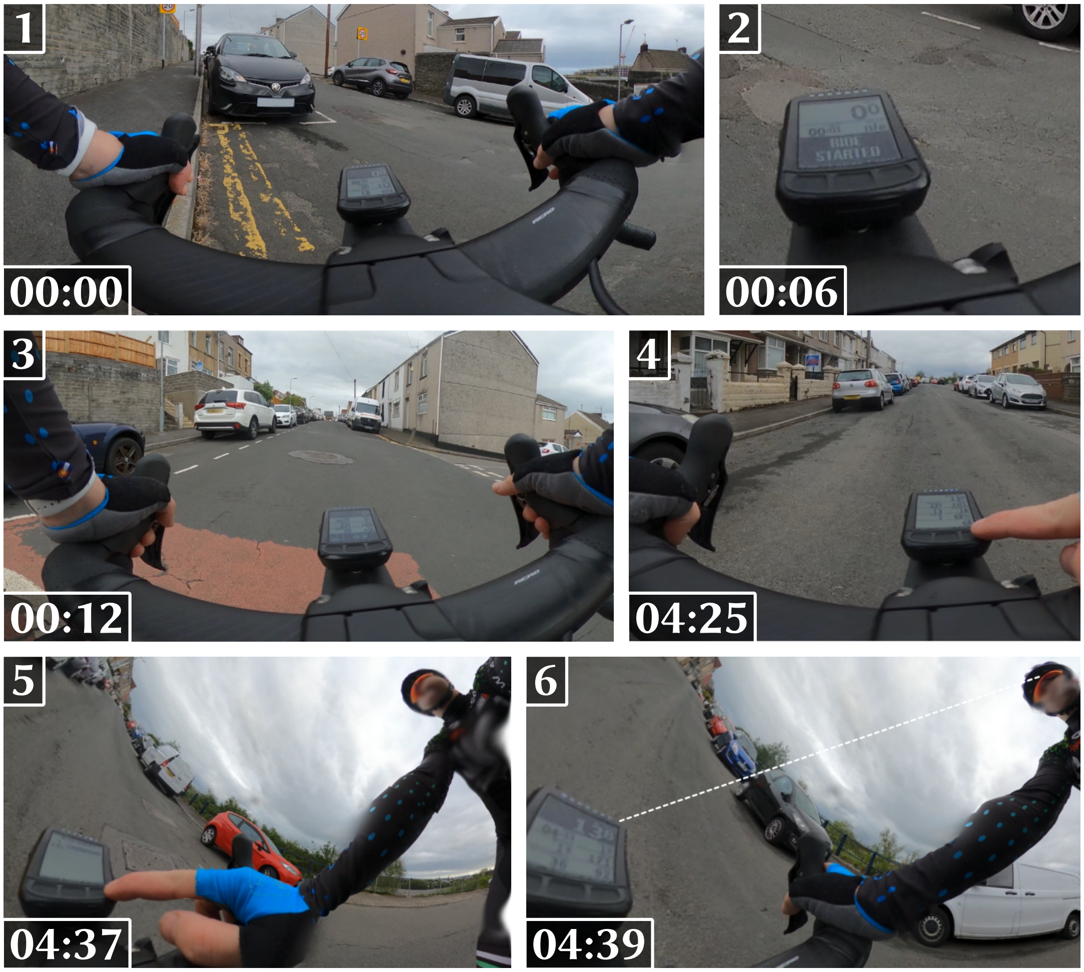

Figure 1: *P1* starts a ride with a computer mounted to handlebars, positioned centrally in front of the bicycle.

4.2 Using a smartwatch

While bike-mounted devices may present themselves as an ideal approach to measuring one's performance on a bicycle, the widespread availability of smartwatches and exercise-tracking devices also afford cyclists similar tracking capability in addition to other functions. The workout tracking functionality on many smartwatches often requires some form of interaction with the device to enable working recording, although may detect and prompt the user with an alert upon automatic detection of exercise activity to enable recording. Additionally, smartwatches often include additional functionality, such as the ability to display notifications and alert wearers of information through vibrations rather than visible or audible alerts.

In this second fragment, as pictorially presented in Figure 2, we consider *P2*'s use of a smartwatch while cycling along a relatively straight, lit, and traffic-free road at night. The road is also smooth, having recently been resurfaced, although there are several raised/humped sections of the road designed to reduce the speed of vehicles at pedestrian crossings. Given the position of the camera, we could not be sure of why or what occasioned a cyclist's use of their smartwatch beyond a speculative inference based on their actions. Most of the time, for the five participants who had smartwatches, we speculated their use as either exercise tracking (based on use before starting a journey) or messaging, as we see next with *P2*. Some interactions may have *merely* been glances at the time, of course.

At the start of this data fragment, we see *P2* cycling through an intersection, with both hands on their handlebar and one earphone inserted into their left ear. As they pass through the intersection, the highway narrows slightly due to a central curb introduced to separate the two directions of travel along the road. Then they rotate their head to look over their right shoulder (step 2). As they turn their head to face forward again, they readjust their singularly inserted earphone in their left ear and return their hand to the hoods of their handlebars. They then bring their hands to be clasped over the handlebar and then bring them to the centre, before momentarily re-adjusting them so that their wrists are on the handlebars only. They then lean back, pulling their left hand with them and leaving the fingertips of their right hand on the handlebar. A second later, they pull back their right hand such that they are sitting upright. Following this, they lift their hands to look at and use the smartwatch on their left wrist. They proceed down the road for four seconds, focusing their gaze on their watch, which is held close to their face. As we end the fragment, they return to their initial position of leaning forward with both hands on the handlebars.

This fragment features mundane elements that many cyclists will be familiar with, irrespective of technology use. For example, checking behind you when a road narrows is essential to ensuring awareness of nearby vehicles: a car behind you on a narrower stretch of road might precipitate a need to move closer to the edge of the carriageway when a car overtakes. The cyclist has corded earphones, with only their left earphone inserted; thus after they return their head to the forward position, they readjust this inserted earphone (it is possible the action of turning their head has loosened the fit of the earphone in the ear). Then we see a remarkable feature in the moments leading up to the cyclist using their smartwatch: they move their hands to the middle of the handlebar and then switch to resting their palms on the bar instead. This act of stabilising oneself is crucial for the next step which they perform: they remove one hand from the handlebar, pulling it back to their torso and then pull their other hand back slightly but within a fingers-reach of the bar, keeping the fingertips of their right hand on the handlebar, as they stabilise themselves. In this, we see the careful preparatory steps the cyclist performs in the moments leading up to their device use: (1) they have checked their surroundings, then (2) steady themselves as they (3) gradually sit upright. Following this preparation, they pull back both hands to their chest, sit up for about 1.5 seconds, before lifting both arms such that their left wrist—on which they are wearing a smartwatch—is in front of their face, and then use their right hand to adjust and interact with the watch. As they complete their device use, we see a staggered return to their original position on the bicycle, as they lean forward and place their hands on the handlebar in the centre. Moments later, they move their hands to the 'drops' of their handlebar and lean further forward, and the sequence of device use is complete.

4.3 Using voice-activated earphones

While technologies with voice-based interaction are often praised for benefits [10] in the home [52], in group interactions in public spaces [54], as well during activities such as driving [31], their use by cyclists seems to be somewhat muted. Although our cyclists had smartwatches or earphones which included such functionality, we did not see many examples of voice-based interaction. Two participants (*P1* and *P2*) ostensibly listened to music while cycling, occasionally adjusting their earphones while cycling (an example of *P2*'s use is in the next section). The use of voice-activated features was confined to just one participant who also demonstrated some challenges in accomplishing this. While the promise of 'eyes-free' interaction is strong [46, 74], technology must still battle with the challenges of ambient noise, something which is especially prevalent with—although not unique to—cycling (e.g., as also found in industrial settings [63] or cockpits [21]).

In this third fragment, we see *P7* use their voice-activated earphones, which include an interactive personal assistant to request a particular song to be played. While we can hear the participant's requests, we cannot hear any response from the device and can only infer what is happening based on the subsequent actions of the cyclist.

While cycling along a shared use path next to a relatively quiet industrial road, the cyclist says "ok google play king of kings by hillsong international on spotify" (step 1). In this request, they use the wake word "ok google"—which activates the voice interface on their earphones, before asking for a particular song by an artist using a specific app to be played. The cyclist here uses a perfectly formatted and complete request, with no ambiguity to the listener of the intent of their action. However, throughout this entire interaction, *P7* attempts to activate their voice assistant multiple times (achieved by using the phrase "ok google") suggesting that the request remained unfulfilled, either due to the voice interface not activating or the system not being able to correctly transcribe or 'make sense of' the request. After their first request fails, *P7* repeats their entire utterance slightly slower, and with greater volume (step 2). After they ostensibly fail to activate their personal assistant again, they tap their right earphone (step 3), now attempting to activate voice assistant manually—this suggests the lack of a perceptible audible response from their device (e.g., this could be caused by the road noice). The cyclist repeats this tap on their right earphone another time, before re-uttering their original request (step 4). Again, however, this seems to fail to work with the participant repeating their actions of tapping their right earphone and re-uttering the request (step 5). It is never clear if the request is successful from the journey.

This fragment demonstrates the challenges of using voice for interacting with technology, and how these challenges are exacerbated by eyes-free interaction designs. Research, even in the home, has found the challenges of regulating one's voice to activate and use a voice interface (e.g., [52]). *P7* has to rely on a minimal response from the device, which is likely to be a low-powered device (i.e., earphones) for determining if the device has activated the voice interface. In an attempt at resolving the 'failed' activations, the cyclist attempts to trigger the voice interface by tapping on their right earphone, afforded by the convenient location (i.e., they can reach their earphone by lifting just their right hand). The cyclist initially attempts to activate the voice interface by uttering the device's wake word, hoping the earphones capture this being said. Cyclists are able to complete this without much effort, simply lifting one hand from their handlebar with no alteration of their gaze. After tapping their earphone, they repeat their request. Requests after the wake word are typically processed on a more powerful device (e.g., locally on a smartphone or 'in the cloud'); however, ostensibly their issues persist. Thus, this raises the prospect that the challenge here is also dealing with background noise from wind and traffic. Furthermore, while many voice-activated devices can feature multiple powerful microphones, wearable devices often have much smaller microphones that are not ideally positioned to capture sound from the wearer's mouth when there is a strong wind. Thus while there is a growing body of work demonstrating the methods through with users debug and 'repair' interactions with voice-activated devices, the resources open to cyclists are restricted to audio-only responses, and the resources for the device to capture such input are also hampered by nature of being placed in the ears of the user. However, the convenience and size of the device means that the cyclist can keep one of their hands on the device for the entirety

Figure 2: P2 uses their smartwatch from cycling along the road

of the sequence, and crucially, return their hand to their device in between attempts to activate the voice interface by tapping.

4.4 Using a smartphone

In this final fragment, we orient to the use of technology seemingly attracting the most mainstream criticism: the use of a handheld portable device such as a smartphone (e.g., [47]). While many jurisdictions are progressively legislating against the use of such devices while driving, laws in the UK, for instance, do not prohibit cyclists from using a smartphone while cycling, including on the road [47].

Five of our participants used a smartphone at some point during their recorded journeys. Three of the participants did this while stationary, typically at moments on their journeys when they were stopped at shops or cafés during their journey or when waiting for a fellow cyclist to catch up. As they stopped for other purposes, they retrieved their smartphone to either make calls, inspect data collected during their journey, or examine a map. In one case, a

Figure 3: P7 attempts to use their voice-activated assistant through their wireless earphones

cyclist called someone back on their smartphone who had called them while they were cycling. During the study off-boarding, we discussed with our participants whether they always carry their smartphones; all our participants stated they typically did carry their smartphones, often in a jersey, pocket or rucksack. In our corpus, we saw a mixture of smartphone use while stopped and while in motion—some cyclists (*P1 and P6*) only used it while stationary, while two (*P2* and *P4*) used a smartphone while in motion, on both a shared pedestrian/bicycle path and on the highway.

In the following fragment, depicted in Figure 4, we focus on *P4*'s use of their phone as they are cycling. A minute or so into the ride, they turn off of a side road near their home and onto a rural road through a village (step 1). After they turn, they pedal slowly and move their hands onto the centre of the handlebar. They then retrieve an energy bar from the back pocket of their jersey using their right arm while keeping their left hand on the handlebar (step 2). They bring their right hand—with the energy bar—to the handlebar (step 3), and then with their left hand, take the bar and move this to the back left pocket of their jersey (step 4). Next, they take their smartphone from the left back pocket and bring this in front of them, reversing their previous actions to put their smartphone in their back right pocket. However, they then bring their right hand forward again, still holding their phone. They bring the phone up to their eye level—keeping their left hand on their handlebar as they use their phone with one hand (step 7). After a few seconds, they pull their phone down, before inserting it into their back pocket (step 9). They return both hands to the centre of the handlebar, before moving them to the hoods, leaning forward and cycling faster.

In this sequence we observe a cyclist on a regional road moving items around in their pockets, employing similar techniques to what we previously observed in the fragment on the use of a smartwatch (see 4.2). Cyclists can manage their stability by bringing their hands to the central section of their handlebars and progressively handling devices (or other objects, in the case of the energy bar) with one hand at a time. Additionally, rather than shift their gaze downwards, we note how the cyclist brings their device up to their eye height. However, the portability and afforded ability to hold and use the smartphone in one hand enabled the *P4* to keep one hand on the handlebar to ensure stability. Following their use, before placing the device in their jersey pocket, they can again gaze forward while cycling, holding on to the bicycle with one hand and holding the device with the other, before placing the device in their jersey pocket.

We must also contrast with *P2*'s use of a smartwatch in 4.2, in which they removed both hands from the bicycle to use their device, whereas the smartphone interaction here was completed with one-handed interaction. This demonstrates the affordance and importance of one-handed use in cycling. While our literature review and preconceptions of wearables suggested that they enabled easier and less obtrusive use for individuals, a smartphone demonstrably enabled the cyclist to keep one hand on their bicycle throughout their use of the device (as did the bike computer and earphones). We intentionally avoid any direct comparison here over which is the 'better' interaction (or whether our observations of smartwatch and smartphone interactions were desirable) but nevertheless orient to this feature of smartphone design not matched by smartwatches, and one which adds complications to existing literature that discusses the benefits of wearable technologies in comparison to handheld devices.

Figure 4: P4 uses their smartphone while cycling on a road

5 DISCUSSION

Above we presented our findings as a series of fragments from our corpus. We provided thick descriptions that explicate the actions of the cyclists in the moments leading up to, during, and following their device use. We did this by adopting an ethnomethodological lens, drawing upon our own experience as cyclists, to understand the actions being accomplished. We now synthesise our fragments, and discuss their implications on the use of technology in cycling, how this relates to existing literature, and what our findings mean for the design of future technologies.

5.1 Self-selecting moments of technology use

Although using a device while cycling is treated as an unsafe act [47], by orienting to cyclist's interaction methods we have explicated the interactional work by cyclists to ensure their stability while cycling and using a device. Cyclists, across all four fragments, performed actions before their device use, checking their surroundings and ensuring their stability. Except for the use of the bike computer (subsection 4.1), periods of technology use typically required removing at least one hand from the handlebar, whether it to glance at smartwatch (subsection 4.2), to tap an earphone (subsection 4.3), or to hold a smartphone (subsection 4.4). As a result, across our corpus and through debriefings with our participants, cyclists ostensibly did not use their devices while cycling 'fast' when needing to take their hands off the handlebars, mirroring findings with walking and using a device [6]. In the case of the smartwatch, the cyclist checks their surroundings first and pedals slower as they use their watch. With smartphone use, we see the cyclist pedal slower as they move items around and then speed up as they finish their device use. This suggests that cyclists ostensibly adopt an approach to greater awareness of their surroundings, and moreover, *select* moments when they were able to use the device with one (or no) hands on the handlebar.

Furthermore, in contrast to the literature on interruptions, which often shows people responding to notifications quickly [50], we note how people in our study primarily self-selected these moments to use their device while carefully attending to the exigencies arising from cycling. Our cyclists often made use of stops, especially when cycling in groups, to use some form of technology, although we have not presented any fragments here exemplifying device use while stationary, in part for sake of brevity we have focused on the salient examples in our corpus. We did not consider it a particularly revealing insight that cyclists in our study typically carried a smartphone with them—smartphones provide vital information for cyclists as for everyone else, given their aid in terms of navigation and the ability to call for help should one needs it. Our intention with this paper was to demonstrate the nuance of using a device, including a handheld smartphone, on a bicycle: cyclists routinely demonstrated cognisance of the dangers of using a device and thus *self-selected* the opportune moment to use their device. Cyclists did use their device when stationary at times (as we mentioned above), but they also self-selected moments to use this while cycling without stopping (as can easily be done at the side of the road or on a pavement). This implicates that cyclists in our study felt able to use their device while cycling, and took preparatory actions before doing so. Thus, our research shows how cycling and using one's device involves a significantly nuanced and intricate series of actions. We suggest that if such choreography by the cyclist can be sensed and modelled, interactions with digital devices on the move may be radically enhanced. As we discuss below, our data points to the handlebars as being an area of bikes that might play a key role in such approaches.

5.2 The zonal nature of handlebars

The use of hands and arms remains an important aspect to consider in cycling, with arms used as the primary international standard for signalling to others around the cyclist [68]. Across our fragments examining the bike-attached computer, smartwatch and smartphone, we orient to the importance of the *use* of the handlebar in each sequence of using a device while cycling. In particular, cyclists in our study typically placed their hands at the extremities of the handlebar while cycling (edges, hoods or drops), and then brought one or both hands towards the centre of each handlebar prior to using a device with one or both of their hands. Conversely, after using a device, we witnessed a reversal of this sequence: cyclists typically first returned their hands to the centre of handlebars, and then further moved them to the extremities of the handlebar, as they shifted their focus back to their cycling from the device use. Thus we remark upon how the handlebar is treated by cyclists as a *zonal* space, whereby cyclists can place one or both of their hands at either the extremities, or in the centre of the handlebar. The *transition* of cyclists hands between these zones bookend the use of devices by cyclists.

This zonality and the transition between zones is important for cyclists, it enables them to ensure their stability on the bike—we also posit that such actions hold the potential to become even more involved sites for digital interaction. In other words, these transitions may offer moments whereby future digital handlebars could respond. Existing research has examined the augmentation of handlebars to provide information *to* cyclists, e.g., by providing vibrations through handlebars to aid navigation, although with limited success [42]. There have also been handlebar-mounted devices developed, e.g., to enable cyclists to provide input to signalling systems [14], or for capturing micro gestures in a way such that cyclists keep their hands statically at the extremities of handlebars [65, 73]. However, our findings suggest that cyclists are competent to move their hands between these different zones of handlebars and that these larger-scale transitions should be considered viable options to provide input to digital devices while cycling. A future 'digital handlebar' might respond to cyclists moving their hands between zones and activate unique modes on connected devices, or even use this as triggers to safety features prototyped in research, such as smart helmets [71].

5.3 Limitations and further work

A limitation of our approach here is our focus on the accountable actions of cyclists only. That is, our findings are formed from only what we can observe and make sense of as cyclists ourselves. While this approach and orientation enabled us to unpack cyclists' actions and reveal the subtleties through which cyclists use a device, it of course means that the intricacies of wearable technologies—which often make use of vibrations to communicate with the wearer—are not captured and we cannot remark upon due to their lack of visibility. It is possible we also failed to hear audible sounds from devices if these were drowned out by ambient noise. However, we accepted the benefit of observing 'natural' interactions without the researcher present or any interventional data collection, in part due to COVID-19 restrictions but also as a benefit to the groundedness of our data. Further work might seek to adopt a hybrid approach with additional mechanisms to capture data from cyclists' technologies such as logs or screen recording (as others have done with smartphones [7]).

A second limitation, which we touch upon above in 3.1, is that all our participants self-identified as men and had a relative competency in cycling. A future study should also consider casual and tourist cyclists, as well as recruiting participants of different genders.

A final limitation is that, although we are based in a Western European country, we asked cyclists to cycle as part of their normal routine only and, due to COVID-19 restrictions, were unable to conduct our observations in different climates. Although we are cognisant that there is a strong need for HCI to focus more on climates with tropical, dry, or arctic conditions, here we conducted this study in our own local geography [34]. At times, our participants did cycle during inclement conditions (strong wind and rain) although by the nature of our participants only recording journeys they would usually take, we did not record many of these journeys. We would encourage others to conduct similar observations in different climates, and we ourselves are working on collaborations to undertake this.

6 CONCLUSION

In this paper, we have presented an empirical study of people's use of technology while they are cycling on their bicycles. By attaching 360-degree cameras to their handlebars and asking cyclists to record their journeys, we collected nearly 18 hours of footage. By adopting an ethnomethodological approach to our study, we orient to the interactional work of cyclists in the moments leading up to, during, and following their device use. We presented four fragments as exhibits of our corpus, with our cyclists using smartphones, smartwatches, voice-activated earphones, and bike-mounted computers. These fragments enabled us to explicate how cyclists prepare to use a device by ensuring their stability using the handlebar and unpack the idea of 'using a device on a bike'. While this is often treated as a single activity, our research shows this is, in fact, a series of intricate steps undertaken by cyclists. By examining these actions, we observe how they ostensibly select moments during their journeys, demonstrating a level of care and precision to using a device on a bicycle, and we examine this in the context of literature on multi-modal device interactions. Furthermore, we discuss the importance of the handlebar, with cyclists making use of central positions—or 'zones'—before and after device use. Through this observation, we discuss opportunities for considering the handlebar as a site for innovation and one which could trigger safety features from other peripherals as cyclists make transitions between these different zones.

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