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RESEARCH

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Impact of cycling infrastructure on cyclists experience and sense of flow in two cities

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Abstract
Many cities seek to increase cycling as part of broader strategies to reduce the reliance on private cars and alleviate traffic congestion. Nonetheless, promoting cycling can be a challenge, as it requires building appropriate infrastructure that offers positive and functional cycling experiences, thus inviting more people to bike. This paper investigates cyclists' perceptions of existing cycling infrastructure to find how the designed infrastructure impacts their sense of flow. Using mobile video ethnography with 30 cyclists in two cities, Gothenburg (Sweden), and Curitiba (Brazil), the study examines how infrastructure shapes their sense of flow and related behaviours. The findings show that cyclists' sense of flow is frequently disrupted in both cities, with similar types of infrastructural disruptions, producing comparable behavioural and experiential consequences. We also find that these situations reflect recurring design tensions, contextual constraints, spatial trade-offs, and institutional capacity of implementations that affect the compliance with the existing infrastructure manuals' recommendations. The paper offers an experience-based perspective on cycling infrastructure, highlighting the value of complementing technical guidelines with more user-centred and designerly approaches that attend to cyclists' functional and experiential needs.

Keywords Cycling, Bicycle infrastructure, Mobile video ethnography, Behaviour, Design, Mobility

1 Introduction

Increasing cycling is one key measure to create sustainable urban transport for many cities, as cycling provides environmental benefits compared to cars, as well as direct and indirect public health benefits. Successful promotion of cycling is often connected to the provision of well-designed and dedicated cycling infrastructure [1], as especially inexperienced cyclists value good infrastructure [2]. Well-designed cycling infrastructure can create consistently good cycling experiences, improve cyclists' enjoyment which in turn can lead to people more frequently choosing cycling for commuting [3], as well as reduce risk of injury [4].

Beyond normative arguments about why cycling infrastructure should matter, a growing body of empirical work demonstrates that changes in cycling infrastructure can measurably influence ridership and mode choice. Recent natural experiments and longitudinal studies show that new or improved bike lanes are associated with increased bicycle use, often with heterogeneous effects by gender and trip purpose [5–7]. Agent-based simulations likewise suggest that infrastructure configurations and network design can significantly shape cycling uptake at the city scale [8]. These studies strengthen the case for treating cycling infrastructure not only as a physical provision, but as a key determinant of whether and how often people choose to cycle. The present study complements this work by examining how cyclists experience that infrastructure in motion and how disruptions to flow shape their behaviour.

It is well-known what constitutes best practice cycling infrastructure; it includes among other things wide separated bicycle lanes, well-maintained surfaces, and large radius curves [9]. However, for many cities, creating this type of infrastructure can be a challenge, as it often must fit into already built-up areas, thus competing with other modes of transport and services [10], as well as be completed on a limited budget [11]. The difficulties in implementing cycling infrastructure that follows best practice guidelines results in bicycle infrastructure that instead of providing a good cycling experience often can affect cyclists' experience negatively [12] – in ways that disrupt their *sense of flow*.

Liu and colleagues [13] describe the sense of flow as a part of the sensory experience of cycling as a factor that frames the cyclists' perceptions of their environment. Cyclists' experience of the sense of flow is a phenomenon that can be identified in empirical studies such as ride-alongs with commuter cyclists, where participants have been observed to seek to keep on continuously moving to be 'in the flow' and try to avoid places of disruption [14]. The sensory experience, where the relationship between cyclist and environment is mediated through movement while not protected by an enclosed vehicle, is what sets cycling apart from other transport modes [13, 15]. It leads to both positive and negative aspects being experienced more intensely [16]. These experiences translate into different needs in relation to urban design than other modes of transport [12, 17]. Sensory experiences in general [18] and flow in particular, are therefore important to understand to design cycling infrastructure [13]. In parallel, ethnographic and mobile methods studies have explored how cycling practices and infrastructures are woven into everyday urban life and embodied movement [19, 20]. Building on this work, the present study uses mobile video ethnography to trace when and how infrastructure disrupts cyclists' sense of flow during their routine trips, linking these disruptions to behavioural responses.

Importantly, planning and transport research has long sought to capture how cycling "feels" through complementary frameworks such as perceived comfort, level of service, and traffic stress assessments [18, 21]. The concept of flow disruption here overlaps with these established constructs but extends them by focusing on the temporal and experiential continuity of movement rather than on point-in-time evaluations of comfort or safety. In this study, the sense of flow is understood as a composite of three interrelated dimensions: a bodily and sensory experience of moving smoothly through space; a cognitive appraisal that movement is continuous and predictable; and a behavioural aspiration to avoid unnecessary stopping or interruptions [13, 22]. While traffic stress and level-of-service frameworks typically assess static environmental features [23, 24], flow disruption can help capture moment-to-moment variations in what interrupts or sustains a cyclist's sense of smooth, continuous motion. As a result, a cyclist may perceive infrastructure as technically safe while still experiencing frequent micro-disruptions that fragment their sense of flow. Perceived safety and comfort are therefore treated not as synonyms for flow, but as factors that may support or undermine it.

Understanding these disruptions, encompassing both continuity-of-movement interruptions and affective responses such as comfort, safety, or annoyance, is critical for designing infrastructure that supports not only technical safety but also the experiential quality of cycling. Although some research has examined how the built environment shapes cyclists' affective experiences [15, 21, 25], further research is needed to deepen understanding of how positive and negative experiences are constituted and how their disruption shapes cyclist behaviour [26].

Previous research has shown that cyclists' search for flow affects their behaviour, ranging from adjusting speed to surrounding cyclists in dense traffic to engaging in actions that may be considered illegal [14]. We define undesired behaviour as actions cyclists take that contravene traffic regulations or conflict with other road users' expectations, typically motivated by attempts to sustain or re-establish their sense of flow. Although such behaviours may appear unpredictable and dangerous to others, they are often experienced by cyclists as rational responses to infrastructure that fragments their movement [27]. Studies further indicate that these behaviours are largely shaped by how infrastructure design interacts with cyclists' sense of flow [20, 27, 28].

The aim of this paper is to further knowledge about how cyclists experience cycling infrastructure and why these experiences result in "undesired behaviour", specifically, it addresses two research questions:

- When and how does cycling infrastructure disrupt cyclists' sense of flow?
- How do disruptions of flow shape cyclists' behavioural responses?

In addition, we begin to explore why these flow-disruptive designs exists and suggest ways to create less disruptive cycling infrastructure solutions for cities and municipalities struggling to implement best practice bicycling infrastructure against space and budgetary constraints.

2 Method

The study comprised two sequential phases. Phase 1 used Spinney's mobile video ethnography [20] with 30 cyclists in two cities, Gothenburg and Curitiba, to directly observe and record how infrastructure shapes cycling experiences and disruptions of flow. Phase 2 encompassed an analysis of the causes of these disruptions and the reasons for their existence. This two-phase approach, grounded in mobile ethnographic methods, follows established practices in cycling research that use ride-alongs and observational data to inductively examine how environmental factors shape cycling experiences across different contexts and cyclist profiles [21, 29–31]. The mobile video ethnography method allows researchers to capture embodied experiences of cycling in real-time, documenting both environmental encounters and the cyclist's immediate reactions, offering fine-grained, context-rich insights into the mechanisms behind observed disruptions [20, 21].

2.1 Study setting: Cycling infrastructure in gothenburg and curitiba

The study compared two cities with markedly different levels of cycling infrastructure development and cycling culture. Gothenburg, Sweden has a relatively high bicycle mode share for a non-Dutch/Danish context, with around 7% of daily trips made by bicycle and a municipal target of 12% by 2035 [32]. This share, together with a long-standing policy commitment and an extensive network of separated bicycle lanes and shared paths (approximately 800 km), positions Gothenburg as a city where cycling is moving from a niche towards a more normalised, everyday mode of transport [33–35]. Curitiba, Brazil, by contrast, has undergone more recent cycling infrastructure expansion, resulting in a fragmented network of about 250 km with inconsistent standards and an estimated bicycle mode share of roughly 3% of trips [36], characteristic of a "starter" or low-maturity cycling context facing strong competition from motorised modes and other spatial demands [33–35].

Both cities cover comparable areas (448 km² and 435 km²), but Gothenburg has about 600,000 residents compared to Curitiba's 1.8 million [37, 38]. Although much of the cycling infrastructure is formally shared with pedestrians in both cases, the extent, continuity and perceived quality of the network differ substantially. These two cases were therefore selected to illustrate contrasting implementation contexts - one where cycling has an emerging but still modestly normalised role in everyday mobility, and one where cycling remains a minor mode - and to examine how cyclists experience disruptions to their sense of flow across different levels of infrastructure and cycling-culture maturity [34, 35].

2.2 Methodological positioning

Studying urban cycling "holds unique challenges (.) due to hazards of riding in the city and the unique skills and styles displayed within different cultures" [20, p.162–163]. This approach builds on established mobile ethnographic methods in cycling research, where participants video-record their journey on the move (hence mobile) and later talk through their practices while watching the videos, enabling researchers to overcome what Spinney calls 'the challenge of fluid locations' which occur when studying aspects of mobility. The author points out that using mobile video ethnography can be a way of 'seeing there' and 'feeling there' for researchers [20]. Recent studies like those on bike-sharing experiences [31] and environmental influence on older cyclists demonstrate how ride-along methodologies can capture context-specific cycling experiences [29]. The mobile ethnography method combines video recording with post-ride interviews, allowing systematic documentation of disruptions to flow across different infrastructure types and cities, while maintaining the ecological validity of capturing cyclists' real-time experiences [20, 21].

Everyday cyclists' experiences can help us build expertise on why cycling flow is disrupted, but for this study we specifically aimed to recruit a share of participants that had started cycling in both cities within the last 6 months. The motive for including participants that were relatively new to everyday cycling, or at least were new to the targeted cities, was to get a "fresh look" at the infrastructure. We assume, in line with behavioural research, that cyclists with more experience have formed habits, learned responses which become automatically activated, thereby diminishing conscious awareness of the specific actions involved [39]. This reduced awareness may lead to the oversight of critical details that could influence the extent to which cycling is adopted or avoided by the broader population.

2.3 Participant recruitment

We recruited participants using advertisements in internal university newsletters, flyers in bicycle repair shops in both cities, flyer tags on parked bicycles in target areas in Gothenburg, as well as through social media in Curitiba. The target areas in Gothenburg were the areas where the municipality was studying how to promote cycling more intensely. The addition of social media in Curitiba was due to low response rate through the other advertisement methods. People interested in participating registered through an online form. Due to GDPR and ethics concerns, we limited the information requested on the form to what was needed for the project, asking for their contact details, frequency of ride per week, average distance, self-report of cycling experience in the city, and type of bicycle. From 49 responses in Gothenburg and 20 in Curitiba, 21 and 11 participants were selected, respectively, based on cycling experience in the cities and aiming for a balanced sample in terms of bicycle type and gender. From the 11 recordings from Curitiba, 2 participants dropped out of the study, reducing the number of participants to 30 in total.

The recruitment strategy, which relied heavily on university channels and cycling-related networks, resulted in a sample that was predominantly composed of university students or graduates and individuals with relatively high educational level. This likely overrepresents cyclists who are more engaged with mobility issues and may have different risk perceptions, advocacy orientations, or everyday travel patterns compared to the general population. Education level and affiliation with academic institutions have been associated in previous work with higher propensity to cycle and greater awareness of transport policy debates [40], suggesting that our participants may not be fully representative of all cyclists in Gothenburg and Curitiba.

The mobile video ethnography, conducted from May 2022 to January 2023, involved 30 participants who each video-recorded one routine cycling trip, typically their commute. Using a GPS-equipped video-camera (Garmin VIRB Ultra 30), provided by the research team, mounted on the bicycle's handlebar. Following the recordings, each participant took part in an individual session in which they reviewed their trip alongside the researchers. During these sessions, the video was paused whenever participant wished to explain the experiences or behaviours in greater detail, as well as when researchers sought clarification or elaboration. A semi-structured script was also employed to encourage participants to expand on their perceptions of flow, safety, and comfort, but also on their behaviours, emotions, and possible conflicts with other road users.

The video ethnography sessions were fully transcribed and timestamped. Relevant screenshots as well as short video excerpts of the places and situations referenced by participants integrated into the transcript. This procedure aimed to identify and interpret recurring instances of disruption in how and when the experience of flow was disrupted. These instances were coded according to cyclists' reported perceptions, with codes deriving both from participants' direct statements and from observations made during the analytical process.

The analytical process followed an iterative, team-based qualitative approach. One researcher reviewed the initial subset of transcripts and video excerpts to identify recurrent situations in which participants described or displayed disruptions to their sense of flow. From this material, an initial codebook was developed that specified disruption types, contextual conditions, and behavioural/emotional responses. The remaining material was then coded using this evolving codebook, with regular joint meetings to refine category definitions, collapse overlapping codes, and add new codes where necessary. Discrepancies in coding were resolved through group discussion, with particular attention to privileging participant interpretations when they diverged from initial researcher assumptions. We did not calculate formal intercoder reliability coefficients, but the combination of iterative refinement of the codebook, and ongoing peer debriefing within the research team served to enhance the credibility and consistency of the coding process.

In the second stage the coded data were analysed to identify broader patterns of infrastructure aspects that disrupt flow. The aspects were then compared to existing manuals for designing and building cycling infrastructure, both local manuals from each city but also the CROW Manual [9]. We aimed to identify the underlying causes of the problems to understand if they related more to omissions in the existing available guidelines or if it was a matter of improper implementation. The findings led us to try to dig deeper into the matter. For that, we scheduled and conducted two meetings with the municipalities' employees responsible for cycling in the city, one in Gothenburg and the other in Curitiba. The meetings were conducted the same way, with a brief presentation of the findings and an overall discussion about the situations presented, and each lasted about one hour.

3 Findings

The results are presented in four sections: an overview of the participating cyclists and their routes; the infrastructure details that disrupt cycling flow; the consequences of these disruptions in terms of cyclists' behaviours and emotional responses; and the investigation of their underlying causes. The subsequent sections also present the discussions, limitations, and conclusions of this study.

3.1 Cycling paths

The project involved 30 participants, 21 from Gothenburg and 9 from Curitiba. Table 1 gives an overview of their everyday paths (length and type – if they cycled using bicycle infrastructure or not) and in terms of their experience in cycling (experienced cyclist, new to everyday cycling or, new to the cities where the study was conducted). In the recruitment form where participants self-reported their experience, we defined experienced cyclist as a person who has carried out everyday cycling for more than six months. In both cities, a third of all participants were new to cycling or new to the city.

Notably, in Gothenburg 5 participants had e-bikes, and a total of 146 km of cycling was recorded, while in Curitiba, all bikes were regular bicycles, and the distance cycled was 70 km. The average distance cycled per participant were similar in both cities, 7 km in Gothenburg and 7,8 km in Curitiba, ranging from 3 km to 13,7 km and from 3,8 km to 11,6 km respectively.

The maps of the two cities, containing an overview of the participants' recorded cycling journeys is presented on Fig. 1. The cycling network is depicted in blue thin lines on the maps, and each cyclist is represented by a different colour in thicker lines,

Table 1 – Participants of the mobile video ethnography study

Participant – City Gothenburg – G Curitiba – C	Type of experience (self-assessed)	Everyday cycling distance – one way (km)	Approx. % cycled in cycling infrastructure
P1-G	Experienced cyclist	5,8	Between 75% and 90%
P2-G	New to cycling	5,3	More than 90%
P3-G	Experienced, but new to the city	5,3	More than 90%
P4-G	Experienced cyclist	11,2	Between 75% and 90%
P5-G	New to cycling	13,7	More than 90%
P6-G	Experienced cyclist	6,8	More than 90%
P7-G	Experienced cyclist	6	Between 75% and 90%
P8-G	New to cycling	9,2	Between 75% and 90%
P9-G	Experienced cyclist	7,5	More than 90%
P10-G	Experienced cyclist	8,7	More than 90%
P11-G	Experienced cyclist	9,3	More than 90%
P12-G	Experienced cyclist	3	Between 50% and 74%
P13-G	Experienced cyclist	11,8	More than 90%
P14-G	Experienced, but new to the city	6,5	More than 90%
P15-G	Experienced cyclist	3,6	More than 90%
P16-G	Experienced cyclist	8,8	Between 75% and 90%
P17-G	Experienced, but new to the city	3,8	More than 90%
P18-G	Experienced, but new to the city	5	More than 90%
P19-G	Experienced cyclist	4	Between 75% and 90%
P20-G	Experienced cyclist	5,5	More than 90%
P21-G	Experienced cyclist	5,3	Between 75% and 90%
P1-C	New to cycling	10	Between 30% and 49%
P2-C	Experienced cyclist	8,1	Between 30% and 49%
P3-C	Experienced, but new to the city	7,4	Between 75% and 90%
P5-C	Experienced cyclist	7,5	Less than 10%
P6-C	Experienced cyclist	4,5	Between 10% and 29%
P7-C	Experienced, but new to the city	11	Between 10% and 29%
P8-C	Experienced cyclist	3,8	Less than 10%
P9-C	Experienced cyclist	11,6	Between 75% and 90%
P10-C	Experienced cyclist	6	Between 30% and 49%

showing that their journeys covered large areas of the cities, and some of the most common cycling routes.

It is relevant to highlight that in Gothenburg, even among experienced cyclists, most of the rides happened in dedicated cycling infrastructure or, on some occasions, on streets designed as shared space with cars. Meanwhile, in Curitiba, the participants did most of their riding (around 60% of the whole recorded commutes) on regular streets and avenues, sharing the road with cars with no access to – or no knowledge of – cycling infrastructure. Sometimes, the Curitiba participants even used areas where it is explicitly forbidden to bike, like the BRT dedicated lanes, including even the non-experienced and the new-to-the-city cyclists. Nonetheless, the aspects disrupting the flow were identified and coded also in those places and are presented in the next section. In addition, this means that in Curitiba some of the situations recorded were much more dangerous for the cyclists from a traffic safety perspective than the ones recorded in Gothenburg.

3.2 Infrastructure-related disruptions to flow

Despite the differences between the cities and their infrastructure, the analysis identified and categorized 16 types of infrastructure-related disruptions to cycling flow, which

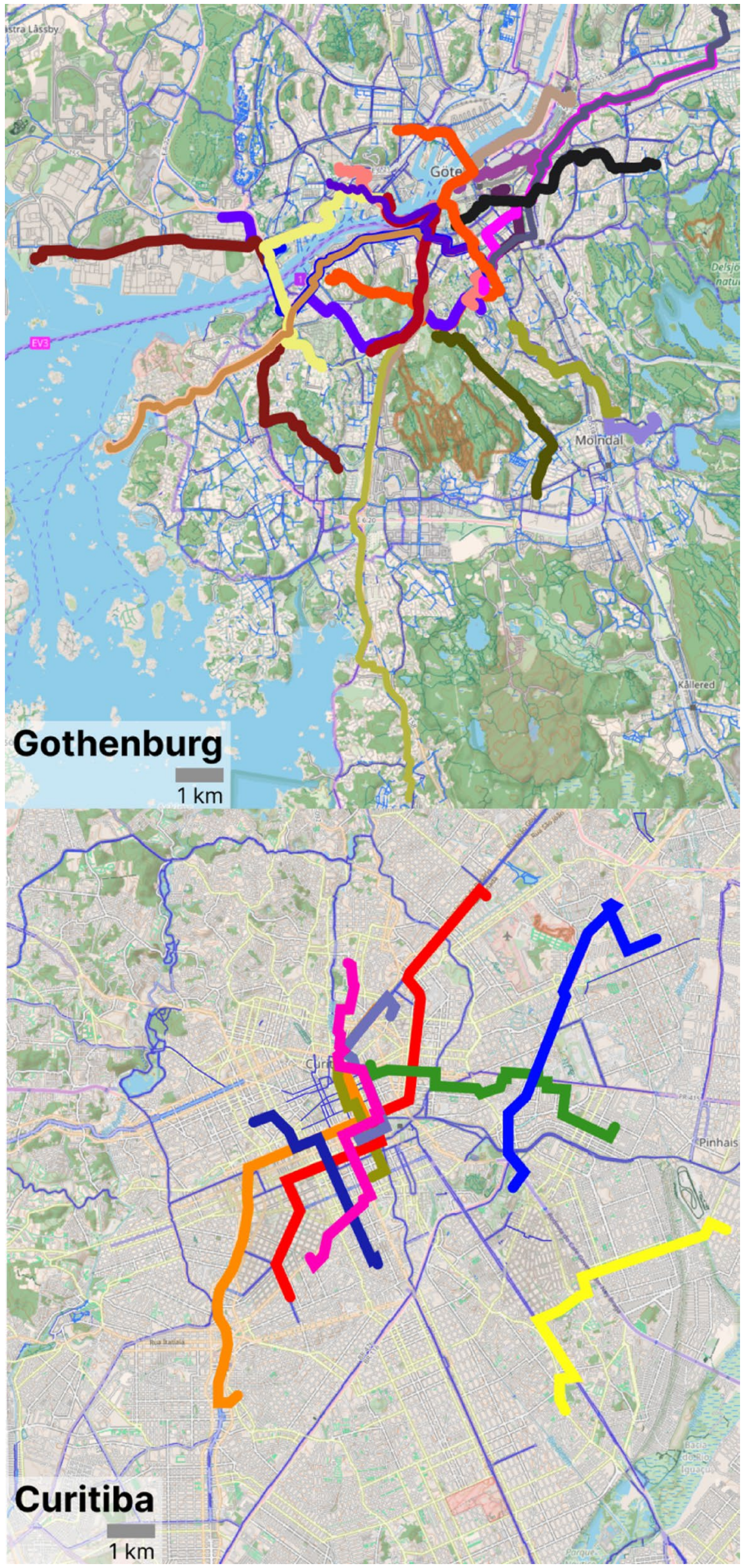

Fig. 1 Overviews of the participants' recorded cycling journeys

followed similar patterns in both cities. The main difference lies in their frequency and intensity: while Gothenburg showed an average of 3.4 places with disruptions per kilometre, Curitiba presented approximately 5.1 places with disruptions per kilometre, where these disruptions were also perceived as more intense. These disruptions lead to series of behavioural and emotional consequences in both cities, that varied depending on the type of disruption, the circumstances, available options, and individual risk perception of the cyclists.

Beyond the similarity in the types of disruptions, the most recurrent categories were also shared by both cities (Table 2). This suggests that the infrastructural factors which most affect cyclists' flow could be comparable regardless of local differences in scale or planning approaches. On the table, the numbers represent the total mentions or visualisations of the disruption type in prevalence order in the two cities. As will be shown, more than one aspect of flow disruption was often present in the same place or situation. For instance, a narrow path further obstructed by an object, or a sharp turn with limited visibility or no space for waiting.

As shown in Table 2, in Curitiba the most common infrastructure-related disruption is the inadequacy or inexistence of cycling infrastructure on the participants' everyday path, which led to the use of the road. Because the cycling network is not very extensive, P7-C, who commutes 11 km one way, riding less than 30% of the way in cycling infrastructure – as it can be seen in Table 1, mentions: "at this traffic light there is a cycling lane that I cross. I could take this one, but it would mean a longer ride with 3 km extra. For me that is a lot, because I already cycle a long distance for going to work. So, I choose a path that allows me to optimize the time and distance I need to cover." In this case, it is possible to assume that the cycling network is not extensive enough and does not meet the users' needs.

The reasons for considering the infrastructure inadequate varied from topographic or route-related aspects, lack of maintenance of the existing infrastructure, traffic and public safety issues, or even personal preferences regarding cycling flow, comfort and experience of the person cycling. In that sense, P8-C states that she rather uses the bus lane (Fig. 2) than the shared with cars cycling infrastructure offered (Fig. 3). For her, the negative traffic safety issues of the provided infrastructure surpass the positive ones. "(...) sometimes they (drivers) sign that they want to turn, they can see I'm coming, and they still don't wait, they just turn, so I must be alert all the time. So, in this case it is very risky because I might need to break hard right on the spot. That's why I don't like this cycling infrastructure".

The lack of cycle lanes or their inadequacy cause discomfort, frustration, and concerns about personal safety and, not surprisingly, lead to cyclists finding different places to bike. Besides riding on street, as seen in the examples, other behavioural consequences

Table 2 Types and prevalence of infrastructure aspects that disrupt flow

Gothenburg		Curitiba	
too narrow	138	inadequate or inexistent infrastructure	122
unclear signs	115	too narrow	112
low visibility	83	too bumpy	98
obstruction	77	obstruction	70
sharp turns	63	unclear signs	49
no space for waiting	47	low visibility	36
too bumpy	45	sharp turns	31

Fig. 2 P8-C rides on the bus lane due to considering cycling infrastructure inadequate

Fig. 3 Screenshot from Google Maps of the cycling infrastructure P8-C avoids for considering inadequate

identified in the data-analysis were riding in the wrong direction on one way cycle routes, or on the pedestrian path/sidewalk.

One thing that sets Curitiba apart from most cities is that Curitiba has dedicated BRT lanes. Even though it is illegal and that the BRT moves in quite high speed, many cyclists feel safer riding in the BRT lanes than on the street, sometimes even when there is cycling infrastructure available. They argue that the cycling infrastructure is shared or have other problems and that in the BRT lane the interactions with buses and other vehicles are scarcer, thus safer.

In Gothenburg, the most frequent infrastructure-related disruption to flow is narrowness and, related to that, P3-G complains: "This is a really narrow cycle path, and sometimes they have these electric scooters, which are parked on them or people walking. So, sometimes I take the asphalt on the left, where the cars are driving. It's really narrow (…) It looks really nice, but if you want to cycle bit faster to work then it is tricky, with a lot of things that can go wrong. And people getting out of their parked cars or cyclists trying

Fig. 4 P3-G perceives this stretch on his everyday cycling commute as too narrow

Fig. 5 P1-C cycling on a shared path for bicycles and pedestrians

to park their bikes, and for a pedestrian it might be not so obvious that there's a bike lane there." (Fig. 4).

With narrowness corresponding to the second most common disruption in Curitiba, P1-C points out: "And here it is shared with pedestrians, you can see a woman with a stroller, she needs to squeeze to one side, and I need to do the same to the other side. Because it is already a very narrow path, and being shared, and bidirectional… There are pedestrians coming and going and the same for cyclists with just one lane. And on the other side of this road/avenue there is nothing, so I need to keep going." He pauses his consideration for a moment and then says: "It is a narrow path, isn't it? But at least there is a path." (Fig. 5).

The narrowness aspect impact on the cyclists' sense of comfort, making them feel annoyed and sometimes irritated, which may lead to cyclists choosing to ride on the street, ride wrong way on the cycling lane, or even having the feeling that they need to "borrow" some of the pedestrian area.

Fig. 6 P2-G registers a temporary obstruction of the cycling path

Fig. 7 P3-C highlights a permanent obstruction in a narrow cycling path

Associated with narrowness, obstruction of the cycling infrastructure was also a recurrent infrastructure-related disruption to flow, being the 4th most frequent complaint in both cities. These obstructions could be temporary as the one registered in Gothenburg, by P2-G (Fig. 6), or permanent, like the one recorded in Curitiba by P3-C (Fig. 7). Nonetheless, they usually narrow the cycling paths or lanes. As P3-C states: "I am riding on the cycling path just to show how narrow it is, because I usually ride on the street, (…) since this (…) is extremely narrow. Do you see? I must ride between the power pole and the lamp pole there. And it is shared with pedestrians and bidirectional for bicycles, but it is impossible to share this cycling path with anyone. That's the reason why I ride on the street, despite not being very safe.".

While in Gothenburg, most obstructions were temporary such as construction indications, tree trimming remains, and snow debris and led participants to feel they need to be more alert, frustrated and non-prioritised. Cyclists handled them usually by riding the wrong way on the cycling lane. On the other hand, in Curitiba, obstructions were

Fig. 8 P7-G points out that it is unclear and even confusing what the cyclist should do at this point

Fig. 9 P3-C register a traffic island that the cycling path crosses with no signage for cyclists

frequently permanent, such as light poles and traffic signs. In this case, cyclists commonly felt unsafe, frustrated, annoyed or irritated, and their compensating behaviours were usually to move out of the designated cycling path.

In addition to having enough width and unobstructed path for a comfortable and safe riding experience, cyclists also need proper guiding and directions to plan their movements and decisions in good time. Appropriate signage is important for people who are new to everyday cycling and are still finding their way, as well as for experienced cyclists, especially when something in the infrastructure changes. For P7-G, for example, Fig. 8 depicts a situation where the signage is unclear and does not help the cyclist to understand how to proceed. The painted official signage – a white arrow – on the pavement points straight forward, while the cycling path crosses the street to the right (as shown by the yellow arrow) and continues as a shared path with pedestrians. P7-G states: "There will be a crossing that it is not signed (…). Can you see it? It's not clear!". Unclear signs are also a problem in Curitiba, at Fig. 9, while riding on a cycling lane, P3-C access a traffic island and doesn't know where she is supposed to position herself for crossing to continue to ride.

The absence of proper signage and the lack of clarity in existing signage are problematic for cyclists, leading to confusion and frustration, but it can also interfere with other road users, creating conflicts, especially at crossings where there is usually interaction with motorized vehicles and pedestrians. Regarding signage, it is worth mentioning that in Gothenburg there are traffic signs and directions specifically designed for cyclists distributed along the cycling paths. Whereas in Curitiba the signage is very scarce, which makes it even more difficult for cyclists to find the connections between the different segments of the cycling network, especially when there is a gap between those segments.

These interactions are also affected when there are too many spots of low visibility along the way, as it happens in both cities. In Gothenburg most situations related to low visibility occur in intersections and are caused by house fences or hedges such as the one in Fig. 10, as well as where there are bus stops along the bicycle paths. For instance, P10-G says "This corner is quite sketchy, you see there is a bush, and the cars are going to come up here (from behind the hedge). (…) and I think there are many places like that, when you have the bushes that are too big, and you won't see the cars coming and they will not see me. So that's not good." In Curitiba, most of the low visibility situations are related to exits of underground parking garages that are preceded by high walls, as depicted in Fig. 11. At this specific place, P10-C had a traffic incident: "There is a wall there, and I can't see the vehicle that is coming up. Once I had a situation, a motorcycle rode too fast out of the garage, and we bumped into each other. Nobody got hurt, but we both had a scare." The problems caused by low visibility make cyclists feel unsafe, uncomfortable and alert, disrupting the sense of flow. It is possible to state that most of the low visibility flow disruption aspects identified are related to the presence of obstacles on the sides of the cycling infrastructure, usually when they are too high or too close of the cycling infrastructure.

Another infrastructure-related disruption that appears as a key factor preventing cyclists from keeping their flow is the way some turns are designed. It is very common that cycling infrastructure is designed with sharp 90-degree turns. To make the situation even worse many sharp turns happen where there is no space for waiting in crossings with traffic lights for cyclists.

For example, Fig. 12 depicts two different angles (a and b) of an intersection close to the university in Gothenburg which several participants complained about. P1-G said: "I hate this, hate it, it is so slow, and it is really strange (…)", while P8-G reinforced with "I mean, if two or three people are waiting it starts to get crowded." A similar statement was made by P7-C in Curitiba about a sharp turn with no space for waiting in her path (Fig. 13): "This part is horrible (…) I really don't like it (…)".

Furthermore, among the most frequent flow disruptions in both cities is bumpiness. As mentioned by P11-G (Fig. 14) "And this part here is where it's going to be bumpy. This part is not built for biking". Likewise, P9-C (Fig. 15) points out: "There is a big defect on the asphalt that is located mainly on the bicycle lane side (…) when it is downhill and there are these kinds of cracks, I end up riding on the street instead.".

The lack of maintenance of cycling infrastructure or even the bad quality of the material used for building leads to physical and mental discomfort while riding, making cyclists feel irritated and annoyed but also underprioritized. In Gothenburg, participants

Fig. 10 P10-G low visibility towards the street from the left because of the bushes

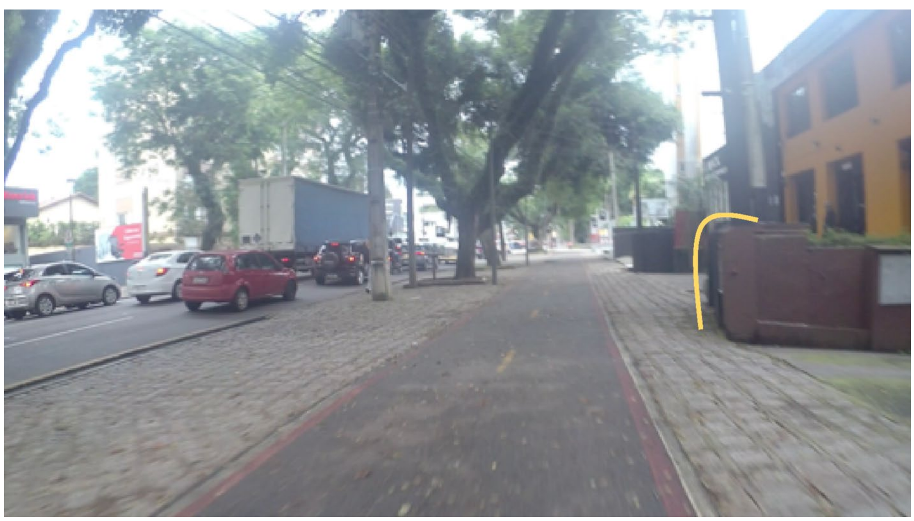

Fig. 11 P10-C low visibility spot on the exit of an underground parking garage

tended to endure these sections at reduced speed, whereas in Curitiba, riders more frequently shifted from the designated lane into motor-vehicle carriageway to avoid it. For instance, as depicted on Fig. 15, the crack on the pavement only affects the cycling infrastructure, which can lead to conflicts with other road users.

In conclusion, while the same disruption categories appeared in both cities, they were more densely concentrated and often more severe in Curitiba, where infrastructure gaps and mixed-traffic segments pushed cyclists towards more pronounced rule-bending and risk-accepting behaviours.

3.3 Conflicts with others

It is possible to see that most of the cyclists' behaviours aim to try to keep the sense of flow when cycling, to avoid putting their feet down and coming to a complete stop. Some of these behaviours can be quite unharmful depending on how busy the alongside infrastructures (streets, other cycling areas and pedestrian areas) are. But even in

Fig. 12 Sharp turn to follow the cycling path and no space for waiting when the traffic light is red

Fig. 13 P7-C sharp turn to the left to follow the cycling path

Fig. 14 Cycling path in Gothenburg with patches and bad pavement

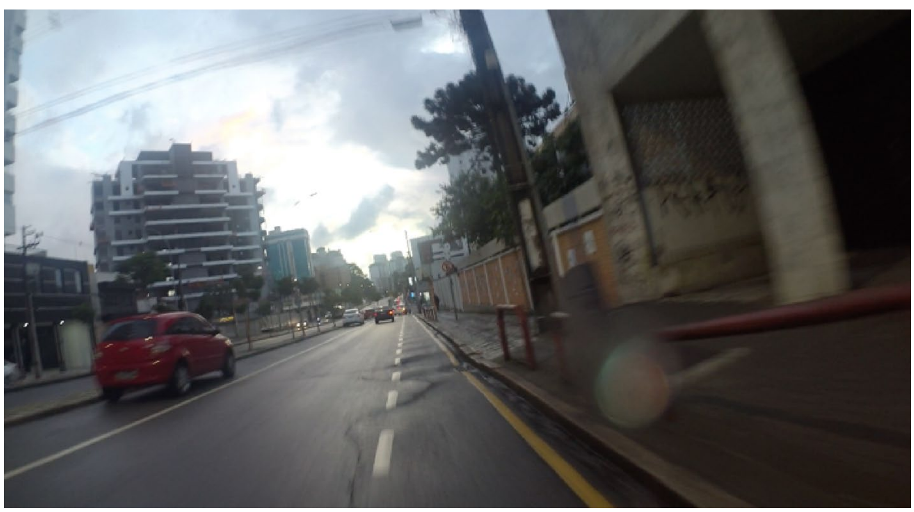

Fig. 15 Cycling lane in Curitiba with a defect in the asphalt on the bicycle area of ride

those situations, they can create conflicts with the other road users of those areas, causing people (cyclists and non-cyclists) to feel irritated and frustrated.

As one could see in the descriptions above, a lot of the consequences of sub-optimal bicycle infrastructure is that cyclists will end up in situations (e.g. cycling in the street) where they eventually have to interact with other people.

These, often unfriendly interactions, especially with motorized road-users, were mentioned by participants from both cities. For instance, in Gothenburg P13-G said "(…) during many years I tried to go with the cars (over the bridge). But people have yelled at me, so much, so I don't do it any longer. I'm so tired of being yelled at, all the time. So now I follow this messy (shared with pedestrians) bike lane, (…) where I need to do so many crossings. It's rather narrow, when I get over to the left side and then I have to manage all the pedestrians, because it is messy also for them." Similarly, P18-G mentioned that "the cars pass by (overtake) quite quickly (…) it feels like you're bothering them". In Curitiba, P6-C admitted that "there are some specific areas where drivers honk behind me or constantly shoot the gas (accelerate disproportionally), making sure I notice how impatient they are (…). Sometimes even when they are stopped at a red light. I try to ignore them (…) I feel nervous and irritated, but also unsafe when they overtake not giving me enough space." Likewise, P9-C pointed out that "at this specific spot I feel that the (drivers of the) cars are really eager to overtake me, it already happened that they honked at me. This is stressful".

3.4 Searching for the underlying causes

To try do identify the underlying causes of the aspects of the infrastructures in both cities that disrupt cyclists' flow, we compared the situations identified to existing manuals for designing and building cycling infrastructure. For that we used manuals from each city and the CROW Manual [9]. We aimed to understand if the patters found related more to omissions in the existing available guidelines or if it was a matter of improper implementation.

Overall, the Gothenburg Cycling Infrastructure Design Manual appears to address most of the situations identified in the city; in other words, many of these issues would likely not have occurred had the manual been fully applied. In contrast, the analysis of Curitiba revealed several gaps in the available design guidelines, particularly regarding the continuity of cycling routes, the treatment of intersections, and the management of shared spaces with pedestrians. Some of the observed situations in Curitiba seemed to result from the absence of clear design parameters, while others reflected inconsistencies between planning intentions and actual implementation.

Nevertheless, as noted in the introduction, strict adherence to design manuals is not always feasible. Cycling infrastructure is often implemented within already dense urban environments, where space limitations, competing spatial demands, and financial constraints hinder full compliance with the recommended standards. Additionally, both cities occasionally allow exceptions to design rules in their manuals, further contributing to variations in practice.

Thus, to try to dig deeper and understanding why the manuals have not been followed, and the reasons behind the absence of directives in some cases, we booked one meeting with each municipality team responsible for the cycling infrastructure. Every meeting lasted about one hour, and they were conducted the same way in both cities, with a brief presentation of the findings and an overall discussion about the situations presented.

In Gothenburg, the meeting was held in a hybrid format at the Traffic Planning Office and attended by approximately 10 to 15 members of the Cycling Safety Group, from various municipal departments such as City Planning, Cycling Traffic, and Parks and Recreation. During the session, short video clips were presented alongside participants' statements illustrating the identified patterns of flow disruption. Most of the locations shown were familiar to the city officials, who explained that many of the issues resulted from older infrastructure implemented prior to current regulations. In some cases, however, disruptive designs resulted from attempts to adapt cycling infrastructure to limited space or to achieve visually appealing solutions.

In Curitiba, we sought to replicate the meeting by contacting several municipal departments potentially involved in cycling planning. However, only the Traffic Planning Office responded and agreed to participate. The meeting, conducted online, was attended by a single city official. It emerged that the City Planning Office employs only two staff members responsible, among other duties, for cycling infrastructure planning. Likewise, within the Traffic Planning Office, the participant and their supervisor were the only personnel assigned to cycling-related matters. Unlike in Gothenburg, we were unable to identify a group similar to the Cycling Safety Group that coordinates work across different municipal departments. The lack of response from the City Planning Office may indicate a limited institutional prioritisation of cycling within the municipality. In contrast to Gothenburg, most of the situations presented were unfamiliar to the participant and would require further investigation and discussion.

4 Discussion

Looking at the whole picture, it is possible to see that the cycling flow is disrupted mostly when design manuals for cycling infrastructure are not followed. The overall lack of consistency in the infrastructure is the main reason for why cycling flow is disrupted. This is particularly interesting since most of these manuals state the importance of consistency for implementing cycling infrastructures [9, 41, 42].

Even though Gothenburg and Curitiba differ in many respects, six of the seven most common flow-disturbing aspects identified were present in both cities, indicating that these aspects can serve as a useful analytical framework for describing flow disruptions in other cities with comparable infrastructure conditions, even if their frequency and salience vary by context. At the same time, the distribution and consequences of these disruptions differ: in Gothenburg they were more often linked to narrowness, obstructions, and ambiguous crossings within an otherwise extensive network, whereas in Curitiba they more frequently stemmed from absent or inadequate cycling facilities and from cyclists' need to appropriate bus lanes or sidewalks, underscoring how similar mechanisms can acquire different lived meanings and policy relevance depending on the maturity, coverage, and institutional context of the local cycling system.

However, there is a distinction in the degree of disturbances. In Gothenburg the condition of the cycling infrastructure is comparatively good, there are cycling lanes and paths almost everywhere one wants to go, and the signage helps cyclists to find and follow those paths. Curitiba, on the other hand, has much less established cycling infrastructure. Thus, the most common disturbance in Curitiba is absence or inadequacy of cycle lane, which is of course much more problematic in terms of possibilities to bike. Furthermore, the level of flow disturbance is in general higher in Curitiba than in Gothenburg. The narrow lanes are narrower, the obstructions more exacerbated, closer proximity to mixed traffic, and lack of signage connecting the different segments of cycling infrastructure etc., which makes cycling more difficult and cyclists' more exposed to risk and conflicts with other road users. Even so, the study has shown that the number of places and flow-disturbing occasions are very high in both cities.

In Gothenburg disruptions on the cycling flow occurred on average every 300 m, and in Curitiba every 200 m, which suggests that disruptions are a frequent and routine feature of everyday cycling in both contexts. Still, in Curitiba, the characteristics and severity of the flow-disruptions aspects pressed cyclists more often towards undesired behaviours. While most situations are easily managed, e.g. by slowing down and being extra careful, the sheer number of occasions makes it inconvenient and annoying. Previous research has shown that cyclists are willing to prioritize routes that offer better experience rather than shorter or faster ones, when they are available [28]. Even so, with every little event, frustration grows which in turn may lead to dangerous decisions and dissatisfaction with cycling as a mode of transport – the disruption becomes the straw that broke the camel's back.

Some situations are also perceived as unsafe. A perception of risk is regularly cited as the main barrier to cycling, and a systematic review found this perception to be closely linked to the quality and quantity of cycling infrastructure [43, 44], as also highlighted by prior research [45]. In this sense, many of the observed flow disruptions can be linked to deviations from design manuals, and full adherence to established guidelines would likely make at least some of these events rarer. At the same time, manuals themselves reflect compromises and do not fully account for space constraints, institutional capacity, or user heterogeneity. In practice, however, the implementation of cycling infrastructure frequently involves exceptions – some anticipated by the manuals, others added ad hoc – which affect user experience and contribute to recurring disruptions. These exceptions also embody the broader perception of cycling as an underprioritised mode of transport compared to cars, a phenomenon noted in previous studies [28, 46].

However, this is not an enforcement issue, nor are the traffic planners intentionally creating bad situations for cyclists. Rather it is a question of there simply not being enough space in cities to follow all design manuals. In this sense, it could be characterized as a wicked problem, where the goal must be to create a solution as optimal as possible rather than aim at perfection.

An additional negative effect of flow disruption is that it affects cyclists' experiences leading to behavioural consequences that often create conflicts with other road users such as pedestrians and car drivers. Some authors state that in the absence of bike infrastructure, cyclists in London "recolonize" the road network by breaking rules [47]. We argue that even though the disruptions in the bicycle infrastructure may be fairly minor in isolation, they end up leading to these rule-bending strategies, or what we have termed 'undesired behaviour', to cope with bad infrastructure. This contributes to the public perception that cyclists are annoying and disrespectful to both traffic rules and other road users as well as the perception that cycling is a dangerous activity, thus hindering new people to start cycling [43].

What may be seen by other road users as dangerous or reckless behaviour and as a traffic safety issue by city planners can, when looked at from the cyclists' perspective, be a source of knowledge to understand and plan for better cycling. The mobile video ethnography method allowed us to see that these rule-bending strategies sometimes become imperceptible to the cyclists themselves once they have turned into habits. Furthermore, our results obtained using this method have highlighted the cyclists' eye-level perspective, their experiences, and their navigation while in motion. We argue that this type of method might be particularly fruitful to emphasize the needs of the cyclists, particularly when addressing situations and places where space does not allow for the cycling infrastructure manuals to be followed. The method could be utilised by city planners and urban designers for "'Seeing There' and 'Feeling There'" [20] instead of being there physically in person (which is more resource-demanding). It allows for the possibility to analyse how cyclists interpret their surroundings, taking into account the speed at which they travel and capturing their social, sensory and spatial experiences [13]. In combination with sensor-based and traffic-stress tools, such qualitative visual methods can help planners interpret why certain locations systematically produce disruptions and conflicts.

Moreover, consulting the manuals reveal that most of them do not show guidelines from cyclists' eye-level perspective and do not consider the motion aspect, offering only an "above" view [13]. Further, these manuals rarely have any cyclists' input [10]. This, along with the fact not all people who plan and build the infrastructure cycle themselves, makes it more difficult to achieve a good cycling experience. To remedy this gap between the unique ways in which cyclists experience infrastructure and the traffic system, and the limited cyclist's perspective present in manuals and among planners, we argue that a more designerly approach is needed.

For instance, we claim that cycling infrastructure guidelines could be more experience-oriented, focusing on functionality rather than minimum measurements, for example: allowing two cyclists to ride side by side without disrupting flow, or ensuring visibility through intersections. Designing in built-up environments is a wicked problem that cannot be solved by strictly following manuals. A more designerly approach involves empathising with cyclists through mobile video ethnography, observations, or co-creative and participatory workshops with iteratively prototyping, testing, and evaluating solutions. Additionally, some research argues that there is value in experiencing cyclists' perspectives via augmented or virtual reality, while low-fidelity prototypes using cones, flowerpots, or temporary signage can also provide practical insights before permanent implementation [13].

To attract more people to cycling, bicycle infrastructure needs to support more than basic connectivity between origins and destinations. The findings show that, in everyday cycling, the experience of movement is frequently fragmented by small infrastructural details that interrupt cyclists' sense of flow. These disruptions accumulate into a poorer overall experience, even in contexts where the network may appear adequate at an aggregate level. Such fragmented experiences help explain why existing infrastructure may fail to support sustained or confident cycling, particularly for less experienced or potential new cyclists.

5 Limitations

Several limitations should be acknowledged regarding the generalizability and interpretation of these findings. Sample characteristics: Our sample comprised 30 cyclists across two cities, with an emphasis on relatively newer cyclists unfamiliar with each city's infrastructure and an imbalanced sample, with 21 cyclists in Gothenburg and 9 cyclists in Curitiba, considering that two Curitiba participants asked to drop out after recording. This composition may not fully represent experienced commuters whose flow patterns and disruption tolerances might differ substantially. In addition, five participants in Gothenburg rode e-bikes whereas all Curitiba participants used regular bicycles. E-bikes affect acceleration, cruising speed, and the effort associated with starting, stopping, and merging, which may influence sense of flow. However, participants reported similar disruptions irrespective of type of bicycle. Nevertheless, the types of bicycles (size, weight, speed) present in the city should be considered when interpreting cross-city contrasts.

Additionally, the recruitment strategy produced a sample skewed toward university-affiliated and higher-educated cyclists, which may limit the transferability of the findings to cyclists with other backgrounds. Further work should aim to include a more diverse set of bicycle types and bicyclists to evaluate whether the exposure to and perceptions of flow disruptions differ.

Each participant completed one recorded trip, capturing a snapshot of experience rather than longitudinal patterns or habitual adaptations over time. This single-trip design strategy does not capture cyclists' perception of flow disruptions that may change with repeated exposure to familiar routes and infrastructure.

The presence of video recording equipment and the think-aloud approach during post-ride interviews may have influenced participants' behaviour and attention patterns, potentially increasing the salience of certain disruptions and making participants more aware of instances where they deviated from traffic rules. While one could suspect that some people choose to not break traffic rules while being recorded, the data suggests that the more common approach was to change behaviour to showcase places that one typically avoided because of how they disrupted flow, giving extended insights into flow affecting situations.

Sensor-based and physiological approaches that infer cyclists' experience from GPS traces, on-bike sensors, or body-worn devices provide valuable large-scale and continuous measurements, but they typically capture proxy indicators (e.g. stress, heart-rate variability) [15, 18] rather than participants' narrated, situated accounts of when and why their sense of flow is disrupted. Our mobile video ethnography is therefore intended as a qualitative complement to these sensing approaches, offering fine-grained, context-rich insight into the mechanisms behind observed disruptions rather than an alternative measurement technology.

The two cities represent distinct infrastructure contexts (a mature Nordic cycling system versus a developing network in a Latin American metropolis). The generalisability based on findings from only two cities is limited. Similar studies in cities with very mature infrastructure and cycle culture (i.e. some Dutch cities), or other cities with intermediate infrastructure maturity levels but markedly different cultural and institutional settings would add potential insights. Still, we find it interesting that two so different cities pose very similar challenges for cyclists' feeling of flow.

In the second phase of the study, we discussed the findings in meetings with municipal officials in each city. While these meetings provided valuable contextual insights, they should not be treated as fully representative of the municipalities' positions, especially in Curitiba where only one official participated. Moreover, presenting findings to officials can invite defensiveness or post-hoc rationalizations, so these discussions are better understood as illustrative reflections than as definitive statements of institutional priorities.

Finally, the analysis did not explicitly incorporate contextual variables such as air pollution exposure, thermal comfort, or weather conditions, which are known to influence cycling experience, perceived effort, and health risks. While integrating such data lies beyond the scope of the present study, we indicate in the conclusions how this could be addressed in future work.

Despite these limitations, the detailed qualitative and video-based material provides rich, situated understanding of how cyclists experience infrastructure disruptions across different contexts, complementing quantitative comfort and traffic-stress assessment tools. The mobile video ethnography approach is not intended to yield statistically generalisable estimates, but rather to identify specific, observable disruption patterns and mechanisms that can inform infrastructure design priorities and guide the use of other sensing-based approaches to cycling experience.

6 Conclusions

This study demonstrates that the quality of cycling infrastructure cannot be assessed solely by network coverage or connectivity but must also account for cyclists' experiential continuity of movement. Through a comparative analysis of Gothenburg and Curitiba, the findings show that recurrent, small-scale infrastructural deviations can disrupt cyclists' sense of flow and contribute to behavioural adaptations and negative experiences. Despite contextual differences between the two cities, similar patterns of disruption were identified, suggesting that such issues are not isolated but systemic. By foregrounding flow as an experiential dimension of cycling, this paper contributes an experience-based perspective that highlights how infrastructure design and implementation shape everyday cycling and influence its broader adoption.

In that sense, as future direction of our research, it would be important to develop experience-directed guidelines, followed by an investigation on how these guidelines could and would be used to help design solutions and fix existing problems through small design changes for making urban cycling more pleasant and safer, and cyclists happier. Additionally future work could extend this approach integrating video ethnography with environmental variables such as air pollution exposure, thermal comfort, or weather conditions exposure, and by examining how flow disruptions and the different environmental/urban/embodied contexts interact to shape sustained cycling adoption across diverse rider profiles and life stages. Another approach could systematically evaluate how different bicycle types (e.g. e-bikes versus conventional bicycles) shape the experience of flow disruptions across diverse urban contexts.

If cities wish to become more sustainable and cycling-friendly, cycling must be treated as a priority rather than merely fitting into the space left over by cars, thus increasing the use of this fun mode of transport and allowing more people with different profiles to bike. This could be partially manifested in smaller changes to the design of the cycling environment to address the uncovered disruptions, but we also see room for a more radical approach where cycling is given dedicated space to grow rather than occupying residual space. This may be crucial in order to attract people who do not cycle today.

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Author contributions
GP: Conceptualisation, Methodology, Investigation, Formal Analysis, Writing; HS: Conceptualisation, Methodology, Formal Analysis, Writing; PW: Conceptualisation, Methodology, Formal Analysis, Writing. All authors reviewed the manuscript.

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Data availability
The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request. The data are not publicly available due to technical restrictions, as most of the files are too large to be shared via public repositories.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with institutional ethical standards and the principles of the Declaration of Helsinki. Ethical approval for this study was waived in Sweden, in accordance with the Guide to the Ethical Review of Research on Humans from the Swedish Ethical Review Authority. In Brazil, the protocol of project was approved by the Ethics Committee in Human and Social Sciences of the Federal University of Paraná (UFPR), which issued the Certificate of Presentation for Ethical Consideration (CAAE 59140522.0.0000.0214). All participants were over the age of 18 years of age and freely consented to participate in this research, all participants were made aware of the purpose and nature of the data collection, all participants were free to withdraw from the research at any stage and were informed in advance, and all data was managed securely and confidentially. All participants provided informed consent prior to participation, including consent for video recording and interviews.

Consent for publication
The authors affirm that all participants were made aware of the purpose and nature of the data collection and provided informed consent, prior to participation, to publish of anonymised materials, including screenshots and/or short excerpts from recorded videos, and quotes from their interviews.

Competing interests
The authors declare no competing interests.

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