ABSTRACT

Bicycle infrastructure is in most cities a fairly recent addition and something that has, in many cases, been squeezed in where space has been available. Consequently, the properties of bike lanes differ a lot between different locations. An observation that is easy to make is that when bike lanes are wide, smooth, and straight, the variation in cyclists’ behaviour is low. When on the other hand there are lanes that disappear, that takes long detours, or are blocked for various reasons, cyclists start to act in a way that from an outsider perspective may look random or at least difficult to predict. This paper reports on a study where 17 cyclists have filmed their daily commute with GPS equipped action cameras. They then observed their film together with a researcher and explained how they perceive the route and how they make their choices in traffic. Based on the results of the study we present a tentative model of how cyclist behaviour can be predicted that can be used as a design tool when designing bicycle infrastructure or making changes to existing infrastructure. The model suggests that cyclist behaviour is affected by two sets of factors; physical factors that can be viewed as unintentional nudges associated with the environment, and subjective factors that are based on rational decisions by the individual cyclist.

Keywords: Bike safety, bicycle infrastructure, perceived action space, ambiguity, predictability, nudging, city planning
1 INTRODUCTION

Cycling is becoming more and more popular as a mode of transport while the car paradigm is challenged, not in the least in the current times of Covid-19. With an increased interest in cycling, there is also an increased number of opportunities for conflicts between people on bicycles and other road users. It is not uncommon to hear people accuse cyclists of acting irrational and unlawful, even though there is no evidence of cyclists being less law-abiding than, e.g., car drivers. In fact, a recent study found that while only 5% of cyclists break traffic laws in intersections, 66% of car drivers do so while driving (Vejdirektoratet, 2019). We argue that the reason for this perception might be founded in the design of the infrastructure, not only in terms of space limitations for different transport modes but also in the ambiguity of the design of the infrastructure.

This study was a part of the EU project MeBeSafe that investigated how small changes in the choice infrastructure, nudging (Thaler & Sunstein, 2012), can affect traffic behaviour. While there are numerous design manuals on how bicycle infrastructure should be designed (e.g., Trafikkontoret Stockholms stad, 2005; SKL & Trafikverket, 2010), the fact is that bicycle infrastructure in most cases is squeezed in where possible which leads to a large variation in design. Our research questions are:

- How do cyclists perceive the bicycle infrastructure?
- How does the design of the bicycle infrastructure affect cyclist behaviour?
2 METHOD

To better understand how cyclists perceive the bicycle infrastructure, and how they reason when they manoeuvre their bicycle, a study was conducted with 17 participants from Gothenburg, Sweden (see table 1). They were recruited by stopping cyclists passing a bike lane and inviting them to participate. Nine women and eight men, with an average age of 46, accepted to partake in the study.

<table>
<thead>
<tr>
<th>Recruitment location</th>
<th>Commuter cyclist ¹</th>
<th>Age</th>
<th>Gender</th>
<th>Type of bicycle</th>
<th>Recorded commute (min)</th>
<th>Interview length (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nobelplatsen (11)</td>
<td>Alex</td>
<td>44</td>
<td>Woman</td>
<td>Bike</td>
<td>22</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Baden</td>
<td>60</td>
<td>Man</td>
<td>E-bike</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Chris</td>
<td>31</td>
<td>Woman</td>
<td>Bike</td>
<td>24</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Dani</td>
<td>47</td>
<td>Woman</td>
<td>E-bike</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Elliott</td>
<td>42</td>
<td>Woman</td>
<td>E-bike</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Finley</td>
<td>43</td>
<td>Man</td>
<td>Bike</td>
<td>13</td>
<td>45</td>
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<tr>
<td></td>
<td>George</td>
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<td>Man</td>
<td>Bike</td>
<td>24</td>
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<tr>
<td></td>
<td>Harper</td>
<td>55</td>
<td>Man</td>
<td>Bike</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Izzy</td>
<td>33</td>
<td>Woman</td>
<td>E-bike</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Jude</td>
<td>66</td>
<td>Woman</td>
<td>Bike</td>
<td>17</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Kim</td>
<td>58</td>
<td>Woman</td>
<td>Bike</td>
<td>34</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Lee</td>
<td>32</td>
<td>Man</td>
<td>E-bike</td>
<td>34</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>57</td>
<td>Woman</td>
<td>Bike</td>
<td>23</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Nicky</td>
<td>67</td>
<td>Man</td>
<td>Bike</td>
<td>16</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Oakley</td>
<td>33</td>
<td>Man</td>
<td>Bike</td>
<td>28</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Perry</td>
<td>48</td>
<td>Woman</td>
<td>E-bike</td>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Quinn</td>
<td>31</td>
<td>Man</td>
<td>Bike</td>
<td>17</td>
<td>45</td>
</tr>
</tbody>
</table>

¹ Pseudonyms.

The participants were asked to travel their daily commute with a GPS-equipped video camera (Garmin VIRB Ultra 30) attached to their bike. The average commute was 19 minutes one way and corresponds to the average cyclist in Gothenburg (Stigell et al., 2018). Next, each participant was invited to an interview where they watched their recording together with a researcher. The interviews were semi-structured and based on the participants’ comments on circumstances observed in the film, see table 2 below.
for sample questions. Topics discussed were, e.g., situations that the participant thought dangerous, pleasant, efficient et cetera, why they perceived the situations this way, and how they motivated their behaviour in different situations.

**Table 2. Sample questions during interviews.**

<table>
<thead>
<tr>
<th>Asked ... watching recording</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>...before...</strong></td>
<td>Could you tell us about your cycling habits?</td>
</tr>
<tr>
<td></td>
<td>How often do you cycle?</td>
</tr>
<tr>
<td></td>
<td>What motivates you to travel by bike?</td>
</tr>
<tr>
<td></td>
<td>Instruction: We’ll soon start watching your recorded commute. We’d like you to think out loud and comment on what we see. We can pause at any time you like. As a reference, you could comment on things that slow you down or speed you up, feels secure or insecure, safe or unsafe or even dangerous, or anything that works well or is a problem for any reason.</td>
</tr>
<tr>
<td><strong>...while...</strong></td>
<td>In response to the participant’s comments: Why?</td>
</tr>
<tr>
<td></td>
<td>How did that situation make you feel?</td>
</tr>
<tr>
<td></td>
<td>When you travelled along this street you did [this], how come? 1</td>
</tr>
<tr>
<td></td>
<td>How did you experience that interaction? 1</td>
</tr>
<tr>
<td><strong>...after...</strong></td>
<td>Which segments of your commute do you (not) prefer to travel? ... Why?</td>
</tr>
<tr>
<td></td>
<td>How come you choose to travel this specific route to your destination?</td>
</tr>
<tr>
<td></td>
<td>Is there anything else you’ve thought about that is not shown in the recording?</td>
</tr>
</tbody>
</table>

1. The participants were given a chance to comment spontaneously on events in the video material. If they didn’t comment on a particular segment, we assumed that the segment was neutral or positive. However, if they didn’t comment on remarkable events, we asked about the event either a few moments later or after the video had ended if we assumed it would influence their following comments on the video material.

The subsequent analysis was conducted on the combined data of the interviews and the video material. The interviews were transcribed, timestamped to match the recording, and analysed via the software NVivo. The data was inductively coded in terms of objective aspects (e.g., objects, people, places, situations) and subjective aspects (e.g., valuation, priorities, feelings). The comments containing the subjective aspects were examined and generalized to a set of subjective factors. In a parallel analysis, the interviews were filtered with a search-query to find comments relating to frequency
Each matching comment and corresponding video segment were examined to identify patterns between the bicycle environment and cyclist behaviour (i.e., trajectory, speed). This analysis resulted in a set of physical factors that influence cyclist behaviour.

3 RESULTS

The final result is a tentative model of cyclist behaviour. It is based on the design and experience of the bicycle infrastructure and describes two sets of factors. The first set consists of nine subjective factors. They relate more to the cognitive process forming cyclists’ perceived action space – the sum of all actions that are perceived to be possible at a certain time and place (Strömberg, 2015). The second set consists of seven physical factors. They relate more to physical elements and can, when combined, represent general layouts of the cyclist environment. Both sets of factors could arguably support predicting how cyclists will act when encountered with a proposed bicycle infrastructure in a dynamic context among other road users (e.g., pedestrians, cyclists, car drivers), see figure 1. Although presented as two distinct components, the analysis that led to them is interwoven. Generally speaking, the physical factors are derived primarily from observing behaviour on video material, while the subjective factors are derived primarily from the transcribed interviews.

![Diagram](image)

Fig. 1. A tentative model of cyclist behaviour. The sum of all factors equals the resulting behaviour.
3.1 Physical factors influencing cyclist action

The first group of factors, influencing how cyclists act in traffic according to our tentative model, are what we call *physical factors* (PF), see table 3 below. They consist of buildings, vegetation, lanes and other physical elements. If placed adjacent to a cyclist lane, each factor either associate with fewer interactions with other road users and less effort for cyclists (PF 2, 4, 7, 6b) or with more interactions and effort (PF 1, 3, 5, 6a, 6c).

Their placement is by intention in design or by chance in practice.

<table>
<thead>
<tr>
<th>Physical factor</th>
<th>Abb.</th>
<th>Description</th>
<th>Examples</th>
<th>Interaction / Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF1) Destinations for pedestrians</td>
<td>D_P</td>
<td>Popular locations where people go to and from</td>
<td>Shops, residential houses, doors in general, bins, benches, school buildings, shopping malls, public transport stops, parked cars¹</td>
<td>More</td>
</tr>
<tr>
<td>PF2) Obstacles for pedestrians</td>
<td>O_P</td>
<td>Longitudinal elements posing as non-traversable barriers</td>
<td>Rivers, high fences, busy highways, back of buildings without doors</td>
<td>Less</td>
</tr>
<tr>
<td>PF3) Obstacles for cyclists</td>
<td>O_C</td>
<td>Elements located on or next to the bicycle infrastructure affecting passage or vision</td>
<td>Holes, ice patches, maintenance holes, uneven ground, edges of asphalt, leaves, gravel, pools of water, fruits or nuts from trees, vehicles, ‘zig-zag’ railing before road crossing, rumble stripes, tunnels, buildings</td>
<td>More</td>
</tr>
<tr>
<td>PF4) Dividers between lanes</td>
<td>V</td>
<td>Elements increasing the distance between lanes</td>
<td>Stones, trees, cobble stones, spacing, railings, fences</td>
<td>Less</td>
</tr>
<tr>
<td>PF5) Elevations for cyclist</td>
<td>E_C</td>
<td>Elevation changes from one point to another</td>
<td>Hills, bridges, high ground to low ground and back to high ground again</td>
<td>More</td>
</tr>
<tr>
<td>PF6a) Lanes for car drivers</td>
<td>L_D</td>
<td>Travel paths for car drivers</td>
<td>Car roads, highways, cyclist boulevards, Shared roads with car drivers and cyclists</td>
<td>More</td>
</tr>
<tr>
<td>PF6b) Lanes for cyclists</td>
<td>L_C</td>
<td>Travel paths for cyclists</td>
<td>Bike lanes, cyclist boulevards, shared roads with pedestrians and cyclists, shared roads with car drivers and cyclists</td>
<td>Less²</td>
</tr>
<tr>
<td>PF6c) Lanes for pedestrians</td>
<td>L_P</td>
<td>Travel paths for pedestrians</td>
<td>Pedestrian roads, shared roads with pedestrians and cyclists</td>
<td>More</td>
</tr>
<tr>
<td>PF7) Shortcuts for cyclists</td>
<td>S_C</td>
<td>Short trajectory segments allowing for easier passage</td>
<td>Segments having less interaction with other road users, with less obstacles, being less uphill</td>
<td>Less</td>
</tr>
</tbody>
</table>

1. Parked vehicles are dynamic destinations: Car drivers are pedestrians after they step out or before they step into the vehicle.
2. This is considered to be the lanes which the observed cyclist is traveling or will travel on, compared to if they’d have to drive where there aren’t any dedicated bike lanes.
3.2 Relationship between physical factors and resulting behaviour

When combined into so-called layouts, the physical factors result in relatively uniform behaviours. These behaviours were so general among the participants that we assume they are linked more to the environment, than the individual cyclist. See figures 2a to 8c for typical layouts and examples observed during analysis of the recordings. We observed that cyclists generally kept to a similar speed if they were able, and perceived it possible, to change their trajectory. If they didn’t perceive it possible, they instead would decrease their speed or stop altogether. The factors which increase effort was observed to result in a trajectory-changing behaviour when placed on one side of a bike lane (see figures 2a, 2b, 3a, and 3b). When placed on both sides, the same factors resulted in a decrease in speed. For example, buildings or vegetation on either side before a crossing, which made it difficult to anticipate traffic, was observed to make the cyclist slow down or delay speeding up until they could see around the corner.

Fig. 2a. Obstacles for cyclists (Oc / PF3). Top: Cyclists are likely to change trajectory to ride more comfortably or safely. Below: Three rugged maintenance holes on the ground to the right acts as obstacles. The cyclist travels to the left.

Fig. 2b. No obstacles for cyclists (Oc / PF3). Top: Cyclists are unlikely to change trajectory as there exist no apparent reason. Below: Nothing acts as obstacles for cyclists. The cyclist travels to the right.
Fig. 3a. Obstacles for cyclists (Oc / PF3). L_D is Car Lane. Top: Cyclists are likely to change trajectory to anticipate crossing traffic (e.g., view-obstructing building). Bottom: The bush acts as a view-obstructing obstacle for cyclists. Cyclist travels in the middle of the car lane.

Fig. 3b. No obstacles for cyclists (Oc / PF3). Top: Cyclists are unlikely to change trajectory as there exist no apparent reason. Bottom: Nothing acts as a view-obstructing obstacle. Cyclist travels in the dedicated lane direction.

Fig. 4a. Obstacles for pedestrians (Op / PF2). L_P is Pedestrian Lane. Top: Cyclists are likely to interact with pedestrians, as they are likely to cross (e.g., shop). Bottom: The narrow low-speed road does not act as an obstacle for the pedestrians to the left.

Fig. 4b. Obstacles for pedestrians (Op / PF2). Top: Cyclists are unlikely to interact with pedestrians as they have less reason to cross (e.g., river). Bottom: The wide high-speed road to the right acts as an obstacle for the pedestrians on the left.
Fig. 5a. Destinations for pedestrian (Dp / PF1). Lₚ is Pedestrian Lane. Top: Cyclists are likely to interact with pedestrians, as they are likely to cross (e.g., bench). Bottom: The bench and bin to the left acts as destinations for pedestrians walking to the right.

Fig. 5b. Destinations for pedestrian (Dp / PF1). Right: Cyclists are unlikely to interact with pedestrians as they have less reason to cross. Bottom: The bench and bin to the right act as destinations for pedestrians walking to the right.

Fig. 6a. Dividers between lanes. (V / PF4). Lₒ/p is either a car lane or walkway. Top: Cyclists are likely to change trajectory in favour of less interaction with other road users (e.g., open car doors, pedestrians entering bike lane). Bottom: The lane edge to the right is an insufficient divider. Cyclist travels in the middle of lane.

Fig. 6b. Dividers between lanes. (V / PF4). Top: Cyclists are unlikely to change trajectory as distance is enough (e.g., arrangement of grass). Bottom: The grass to the right acts as a divider between lanes. Cyclist travels on the right side of lane.
**Fig. 7a.** Shortcuts for cyclists. ($S_C/ PF7$). $L_D$ is car lane. Cyclists are likely to cycle segments with less interactions and effort (e.g., cycling in the wrong arrow direction instead of crossing road twice).

**Fig. 7b.** Travelling to the right across a parking lot that eventually connects back to the bike lane...

**Fig. 7c.** ...instead of traveling straight ahead, slightly uphill and with more interactions with other road users.

**Fig. 8a.** Shortcuts for cyclists. ($S_C/ PF7$). $E_C$ is elevation for cyclists. $L_P$ is walkway. Cyclists are likely to cycle segments with less interactions and effort (e.g., avoiding an elevated crossing).

**Fig. 8b.** Instead of travelling to the left along an S-shaped and narrow road...

**Fig. 8c.** ...the cyclists travel straight forward across a parking lot that eventually connects back to the bike lane.
3.3 Subjective factors influencing cyclist action

The second group of factors, influencing how cyclists act in traffic according to our tentative model, are what we call subjective factors (SF), see table 4 below. They consist of opinions, preferences, experiences, perceived action spaces and other subjective aspects. A few of them relate to self-expression of the cyclists (SF 8, 9) but most relate to the impression of the situation around the cyclist, such as the bicycle infrastructure (SF 1, 2), other road users (SF 5, 6, 7) or a combination of both (SF 3, 4).

Table 4. Cyclist subjective factors (SF) related to bicycle infrastructure (BI) and other road users (ORU).

<table>
<thead>
<tr>
<th>Subjective factors related to...</th>
<th>bicycle infrastructure (BI)</th>
<th>other road users (ORU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>...impressions or external elements</td>
<td>SF1) Ambiguity of BI</td>
<td>SF5) Distance to ORU</td>
</tr>
<tr>
<td></td>
<td>SF2) Reasonableness of BI</td>
<td>SF6) Timing to ORU</td>
</tr>
<tr>
<td></td>
<td>SF3) Ease of sharing BI with ORU</td>
<td>SF7) Understanding by ORU</td>
</tr>
<tr>
<td></td>
<td>SF4) Visibility of ORU from BI</td>
<td></td>
</tr>
<tr>
<td>...expressions or internal elements</td>
<td>SF8) Values and beliefs of cyclist</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SF9) Culture among cyclists</td>
<td></td>
</tr>
</tbody>
</table>

3.4 Relationship between cyclist subjective factors and resulting actions

While physical factors result in uniform behaviours, each subjective factor results in one or more behaviours. The variety of behaviours made us assume they are linked more to the individual cyclist than the environment. Following the more personal nature, the resulting behaviours seem to occur if the individual cyclist perceives a certain action possible and at the same time appropriate or unavoidable. Consider having to cycle along a car lane where there are no dedicated lanes for cyclists. Some cyclists will travel among the cars, some will travel on the pedestrian lane, while some will evade the route completely in favour of streets having dedicated lanes for cyclists. Below, we present
each subjective factor, how it influences cyclist behaviour and provide sample comments from the participants.

The first subjective factor involves the perceived ambiguity of bicycle infrastructure (SF1). The more room for interpretation, such as with ambiguous bicycle infrastructure, i.e., without clear lane markings or directions, the more likely cyclists will approach the same situation in diverse manners. Additionally, this interpretation aspect seems to enhance the effect of other subjective factors.

Quite often bike lanes just ends, I notice, at different locations in town. Suddenly it ends and it is not always obvious where the hell you should go. You just “Oh ok”. Are you supposed to go over here or cycle on the pavement? It is not clear, and it is not uncommon that the bike lane just ends. It would have been nice if there was a sign that said, “Bike lane ends here” or some info like “Continue along here”. Because sometimes you look around, but does it continue somewhere you can’t really see it? I find that annoying. Perry (SF1).

I usually cycle here. I don’t know why it says—Now I’m cycling in the opposite direction of this arrow. I don’t know why I wouldn’t be allowed— I don’t know the meaning of it. Does it mean that I can’t cycle across [the street], or that the cycle lane isn’t meant to be two-way? Which is a mystery to me, because when I cycle [across the street anyway and] to the left here, it says I can cycle and now I am cycling in the direction of [another] arrow. Lee (SF1).

Closely related to SF1 is the reasonableness of bicycle infrastructure (SF2). Travelling from one point to another should preferably be reasonable (i.e., safe, logical, practical) in terms of time and distance. When bicycle infrastructure is perceived less reasonable by the cyclists, they will likely take shortcuts in terms of timing by, e.g., running traffic lights, and distance by, e.g., travelling in an empty opposing lane.

Here there are quite a few cyclists who often slip through here over the parking lot to get and get out over there instead of biking like this. [Interviewer: Why do they do that?]. I think they spare a few seconds. Alex (SF2) (+PF7).
Here I am cycling opposite this arrow [Note: wrong lane direction]. [Interviewer: How come?] This is the side from which I will turn later, and so I’m traveling on this side. I’m fully aware that I am doing something wrong. [Interviewer: So instead of crossing the car lane twice, you—] Yes, perhaps lazy and timesaving, perhaps both. But mostly timesaving, I think, and being a little unlawful [Note: participant laughs] [...] [Interviewer: There is not a lot of traffic on that bike lane.] No, exactly, which is why I feel like I can do like that. Chris (SF2, SF6) (+PF7).

On the other side of the hedge you can see a row of benches, right there. It’s funny how the benches are there, and they have placed the bike lane right where people stand up from the bench. The walkway is on the other side of the bike lane, so the bike lane is in the middle between the walkway and the benches. Why isn’t the walkway next to the benches and the bike lane further away? If you meet anyone from [local traffic office] you could ask them, purely academically, who made that decisions and on what basis. [...] It bothers me since it is such an obvious safety risk to add to all the safety risks among pedestrians and cyclists. Nicky (SF2) (+PF1).

Other road users, not surprisingly, have a noticeable effect on cyclist behaviour. Ease of sharing bicycle infrastructure with other road users (SF3) involves the individual cyclist’s perception of sharing space with others. As stated in the example at the beginning of this subchapter, the behaviour varies. In particular, sharing space with large motor vehicles is perceived as unsafe. Many participating cyclists try to avoid it.

If you cycle on Danska vägen you can cycle ahead to the light here, as you see there. There is a [dedicated] light for cyclists there, so they can cycle across, but I rarely do that, because I don’t like standing—there are often cars very tight by the lights, so—perhaps now, but they can be. [...] And then you have cars on either side of you. It doesn’t feel good. It’s rather tight, quite close. It is definitely better to cycle on a bike lane than to cycle between two rows of cars. Jude (SF3).

All of a suddenly [the bike lane] runs straight out into the car lane. That is really fucking pointless, because what happens is, if there are many cars, that you go up on the walkway. And that is of course not good for all the pedestrians, so it is really odd that [the bike lane] just vanishes. [Interviewer: Do you mean here?] Yes, here. There is the bike lane and then it vanishes there, exactly. And not even a ‘give way’[-sign] or anything. [...] If there are many cars here you will stay in the car lane and be in the way. If you are in a hurry, you go up on the walkway here instead. Baden speaking of SF1, SF2 and SF3.
The perceived visibility of other road users (SF4) is a subjective factor stating that when bike lanes do not offer good visibility of other road users, the cyclists will likely increase their distance to view-obstructing objects. In general, the participant cyclists strive to keep distance to other road users (SF5).

[Interviewer: You said something about cars coming out?] Yes, I mean, cars come from the top left here and also cyclists at a fairly high speed, and they are difficult to see there so I like to keep far to the right here. [Interviewer: Was it the bush that made it difficult to see?] Yes. George (SF4, SF5) (+PF3).

The hill in the grass [by the intersection] is a bit bothersome. I’ve never understood why it has to—why they just can’t flatten it so you see the whole road. Remove it so there is no hill that obstructs the view. Because now you don’t really see [the cars] until you are in the intersection. [Later during the interview:] These lanes are pretty good, since they are so open. You can see the cars coming long before you meet them so to say. Max (SF4) (+PF3).

Here comes an intersection with blocked view to the left. [...] Right there it is good to keep to the right because then you get a better view towards the left. Quinn (SF4) (+PF3).

The motivation for both SF4 and SF5 is that visibility and keeping distance benefits responsiveness to other road users’ behaviour. When visibility or distance is anticipated to be limited, cyclists will manoeuvre to increase distance even if they travelling on the lane for oncoming cyclists or the pedestrian lane.

[Interviewer: I noticed that you rode on the pedestrian lane. How come?] I think I do that because often there’s people coming from the [bus] station there, as there is a station on the other side of the bike lane. Then you keep some distance to—well, there may be kids or people that just walk out in the bike lane. It happens quite often, so I go [here] on the walkway to avoid that. Oakley (SF5).

This street has for the last 20 years I have cycled here, been a bike lane, two-way. [...] the walkway has always been at a lower level. But now they have also made this [bike lane] to also be a walkway. How the hell do they think this tiny, narrow lane which is this wide, can be both for pedestrians and cyclists? Now it is dangerous to cycle there. I almost broke down when I saw it, like “No, now it’s even authorised to walk there”. Perry (SF2, SF3, SF5).
In the same way that the presence of other road users affects behaviour, so will their absence. Cyclists’ **timing to other road users** (SF6) is about seizing, or missing, perceived opportunities. When there are few nearby road users, cyclists will likely be liberal in timing by, e.g., cycling against red lights, and location by, e.g., cycling where there are no intended crossings or bike lanes.

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[Interviewer: I saw that you were in the middle of the track and not on the bike part.] Yes, it’s so empty. It may have something to do with having the bike lane and then you have the cars there, and there can be large vehicles and so on, so you feel a little safer to be further in. **Jude (SF5, SF6) (+PF4)**.

> When I feel completely confident, because I can see far up and far back [and] there is almost no edge there, then I have slipped across here for example. Or a little further ahead. Because I know that—I—it is ridiculous when there is little [traffic] to push the button and pass over there [at the crossing], but when it is rush hour you have to. That’s how it is. **Kim (SF6, SF8)**.

[Interviewer: I noticed that you rode on the pedestrian lane. How come?] I think I do that because often there’s people coming from the [bus] station there, as there is a station on the other side of the bike lane. Then you keep some distance to—well, there may be kids or people that just walk out in the bike lane. It happens quite often, so I go [here] on the walkway to avoid that. **Oakley (SF5)**.

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The last of the subjective factors relating to other road users is the **understanding by other road users** (SF7). How one is treated affects one’s behaviour. When other road users, particularly drivers of large motor vehicles, don’t understand that cyclists are travelling where the bicycle infrastructure tells them to, they appear to treat cyclists with disapproval. Since such situations could become hostile or even dangerous, as recalled by some participants, they try to avoid places where these occur.

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*Here is a segment [driving among the cars] where I feel really insecure, because you are very exposed to car drivers and what attitude they have towards cyclists. Sometimes they stay behind as they should, but sometimes they try to drive by. **Dani (SF3, SF7)**.*
Here I have been scolded by a person that drove up and honked a lot and pointed as if “Hello? You have a bike lane there. What the hell are you doing on the car lane?”. I became so infuriated that I pulled open her car door. [Interviewer: For real?] Yes, but from the passenger side— you should not do that. And I was a bit worried for my sake... that I have, what’s it called when you become really angry while driving a car? Like road rage but as a cyclist. Because she sort of drove up close and tried to mow me off the road. I thought it was so unpleasant that I reacted by becoming so pissed that I pulled up the door and said ‘This is a combined car and bike lane’ with an angry voice. I don’t mean that I pulled up the door, but I pulled the handle — it was locked. That’s what happened.

Izzy (SF3, SF7).

The last two subjective factors relate to internal elements. The values and beliefs of a cyclist (SF8) will make each cyclist approach the same situation differently, especially if there is room for interpretation. For example, when cues on how to act in a specific traffic situation are missing.

[The pedestrian] had no clue I was coming here. I could have pinged at him, but somehow, I try to avoid pinging at people. They may twitch and be— lose their senses, so to speak, so I think it’s a bit foul [of me] sometimes. And I can live with the fact that he has little to no idea I’m coming here. Lee (SP8).

[Interviewer: These situations when it is unclear who should give way, what do you think about them?] Well, my take is that pedestrians, no matter where it is, are the ones you should give way to. And I tend to be good at that, but many become quite surprised when a cyclist stops for a pedestrian. Finley (SF8, SF9).

[The bike lane] ends here, so you must go across. [Interviewer: To the other side of the street?] Yes, and I do it law-abiding like this this time. [Interviewer: How do you mean ‘law-abiding’?] Why, that I am using the bike lane. In normal cases I continue [straight], depending on the traffic, and as soon as I see a gap I swap [sides]. And I work like that almost all the time when I bike that I— it is better to cross the road where there is no traffic than to do it at the correct location when there is a lot of traffic. So I sort of— I often decide myself when I cross a road because it feels good like that. Baden (SF2, SF6, SF8).
However, the culture among cyclists (SF9) makes the behaviour of cyclists converge to some extent. Since culture is tacit, cyclists will likely act in diverse manners before assimilating the cyclist culture in a particular city. In short, behaviours converge due to culture but will differ slightly due to individuality.

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Here we arrive to the intersection [ahead] where the other cyclists come on the bike lane from [the right] over here. [...] When the lights are green it is very unclear who should give way. So oftentimes when you weave together—I mean, cyclists don’t think about giving way between cyclists, you just go. [Interviewer: When speaking of cyclists, do you include yourself?] I also include myself, because I don’t know what’s the deal in this situation. You just have to watch out. George (SF1, SF9).

Here [up the bridge] I cycle on the walkway a lot, in case there are mopeds, e-bikes and so forth. They approach very fast behind you. And I have half the speed they have, but they average 25-30 km/h on the bike lane, so I try when possible to go on the walkway. [Interviewer: How come you choose to do that?] I guess it’s also because you want to—you have to help out in letting others pass. And the same thing when it’s downhill, I think I’m probably in the walkway, because you don’t know what is behind you. [...] There’s a lot of traffic here, as you notice from the road, so you don’t really hear well. Is it a moped [on the bike lane] approaching behind me, or is it a motorcycle [on the car lane] approaching behind me? That’s why it is probably a good idea to keep a bit extra to the right. Oakley (SF6, SF8, SF9).

Although presented separately, the nine subjective factors intermingle with each other.

Similarly, as illustrated by the sample comments, some subjective factors are associated with a physical factor. For example, reasonableness (SF2) with shortcuts (PF7) and obstacles (PF3), visibility (SF4) with obstacles, and distance (SF5) with dividers (PF4).

4 DISCUSSION

We argue that an important purpose of the bicycle infrastructure, besides being a means for transportation, is to converge the behaviour (i.e., position, trajectory and speed) of cyclists. The results suggest that this is not always the case in practice. Several factors (SF 1, 2, 3, 7, 8, 9) hints at a larger theme of ambiguity perceived among both cyclists
and other road users. This ambiguity leads to diverging, and not converging, cyclist
behaviour. One may argue that there is a lack of signifiers (Norman, 2008) for both
cyclists and car drivers, telling them which actions are possible, e.g., when a bike lane
suddenly ends. Some well-deliberated signifiers might very well lessen the ambiguity of
the bicycle infrastructure and make other road users better understand the actions of
cyclists.

However, the study also shows that rules and clear signage are not enough. As illustrated
by the findings, several factors influence cyclist behaviour. What is also clear is that
these factors can be described in isolation to some extent. While cycling, it is the sum of
all these factors in each fleeting moment that influence the resulting cyclist behaviour.
Furthermore, the choice architecture within a city provides multiple ways for cyclists to
cycle from point A to point B. Rationally, any cyclist knows that they are supposed to use
the dedicated bicycle infrastructure. Yet, if staying on the bike lane makes it, e.g., more
difficult to notice nearby traffic, cyclists may instead cycle outside the bike lane –
perhaps into a walkway, car lane or the lane for oncoming cyclists – if there are no
nearby road users. The scenario illustrates how the choice of keeping to the bike lane
includes factors that will affect speed, trajectory or both. How that choice is presented
in the example arguably nudges cyclists out of the bike lane. Since this is not what the
city planners had in mind when they designed their city, this is nothing short of
unintentional nudging. Nevertheless, we do not want to claim that just about any
infrastructure element is nudging per se. There is already a discourse on how measures
presented as nudging, in fact, are not nudging at all (Mols et al., 2014), and we intend
not to contribute to this confusion. Hence, we provide arguments based on the
description of a nudge, as defined by Thaler & Sunstein (2012, p. 6) who popularized the concept:

“Any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid.”

In terms of predictability, the behaviour triggered by the physical factors were common and uniform among the participants, thus quite predictable, while the behaviours triggered by the subjective factors are common but more diverse. Neither of them forbids any options or changes any economic incentives. However, it is a bit more difficult to translate the concept of “easy and cheap”. In the recent example, if a cyclist would stay within the bike lane despite having an obstructed view, they would need to slow down earlier (and at all) before they arrive at the intersection. In a sense, they are “paying” with their speed. Whether this loss of momentum could be considered “easy and cheap”, to avoid the unintentional nudge, is a subjective discussion. For the subjective factors, let us return to the earlier example where cyclists approached the idea of cycling in a car lane. Overcoming your own feelings and going against what you feel, perhaps scared or anxious, could arguably be deemed not easy nor cheap. Thus, subjective factors are not nudges. In brief, they could instead be deemed as deliberate decisions based on the sum of many rational decisions. Still, from an outsider perspective, when observing many cyclists as a layman, it may not appear rational.

All in all, the physical factors are unintentional nudges associated with the environment. The subjective factors are not nudges as they are less predicting and not “easy” to avoid, but instead rational decisions associated with the individual cyclist.
The model presented in this paper is indeed a tentative one. The number of participants is fairly low. Initially, 20 cyclists were planned to participate, but due to Covid-19, we experienced a drop in the number of people who felt comfortable participating, and we ended up with 17 participants. The study was also conducted in one city. It may well be that local conditions affected the results. For example, the types of physical factors that the participants encountered, the local bicycle culture and what is perceived as “normal behaviour” there. For future research, it would be very interesting to include more participants and locations and see to what extent the model still holds.

5 CONCLUSIONS

One of the fundamental purposes of the traffic infrastructure – to create predictability and consensus among road users – falls short by allowing room for interpretation among road users and by specifically triggering diverse behaviour among cyclists. Despite being diverse, and consequently more or less unpredictable, we argue based on our tentative model of physical and subjective factors that cyclist behaviour is rational. The proposed model can be used as a design tool that provides dynamic guidelines and grants better understanding without being too prescriptive. City planners could, for example, explore problems that could arise within a proposed infrastructure layout, according to the model, and then adapt the layout so that the identified problems become less likely to arise. Thus, by understanding how different people interpret the bicycle infrastructure, we can introduce infrastructure that is less ambiguous, more reasonable and that nudges cyclists towards a more uniform and safe behaviour.
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