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Since 2012, the International Cycling Safety Conference (ICSC) has been a forum for scientists and experts whose scientific and practical activities are aimed at making cycling safer. It has offered the opportunity for exchange and discussion, for getting to meet old friends and new collaborators. Over the years, hundreds of contributions have addressed novel research questions and presented innovative practical solutions dedicated to the improvement of cycling safety.

The 2022 edition of ICSC was held in Dresden, Germany, hosted by TU Dresden, together with its co-host BASt. This book contains the extended abstracts of all contributions that were presented at the conference.

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Mileage-based accident risks of pedelec riders

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Keywords: pedelec, mileage-based analyses, accident risk, bicycle, age-differentiated.

1 BACKGROUND AND AIM

In a previous paper, we analyzed accidents of pedelec riders in 2019 and examined possible changes over the past years [1]. We found that pedelec accidents still essentially resemble the classic two-wheeler accident characteristics, with certain specifics (e.g., higher age of riders involved in an accident, higher proportion of single-bicycle accidents, higher proportion of out-of-town accidents). Even though the number of pedelecs and pedelec accidents has increased in recent years, no qualitative changes in the characteristics of accidents compared to previous years seem to have occurred.

We now have a large data base of riders and accidents and new data sources that offer the possibility for calculating accident risks by mileage-based analyses. In addition to absolute accident numbers, relative accident parameters are of particular interest for accident research and prevention. Using the same amount of physical effort pedelecs can be used to cover longer distances than bicycles. At the same time, longer distances increase the probability of being involved in an accident. On average, pedelec users cover 1.8 times as many kilometers per day as bicycle users do [2]. We now have nationally representative data on the mileage of pedelec riders, so we can calculate mileage-based accident risks and get new insight into pedelec accidents. For comparison the accident risks of bicycle riders are used.

2 METHOD

To calculate the mileage-based accident risks, on the one hand, accident data were queried from the Research Data Center of the Statistical Offices of the Federal States [3]. These included all police-reported pedelec and bicycle accidents with personal injury in Germany, both in town and out-of-town (no federal highways). Only riders who were at least 18 years old were included. In 2019, a total of 10,348 pedelec riders and 62,378 cyclists were involved in an accident with personal injury. On the other hand, the data set of the study "Mobility in Germany (MiD 2017)" [4] was used to calculate the annual mileage. The data set contains a total of 7,129 trips by pedelec and 79,221 trips by bicycle, reported by people over 18 years of age.

We calculated the mileage-based accident risk of a) being involved in an accident, b) causing an accident and c) being seriously injured or killed in an accident. For this purpose, a quotient was formed for eight age groups of their share in the total number of a) accident involved pedelec or bicycle riders of all age groups, b) pedelec or bicycle riders who caused the accident of all age groups, c) seriously injured or killed pedelec or bicycle riders of all age groups and their share in the total mileage by pedelec or bicycle riders of all age groups.

If the quotient takes the value "1", the accident risk of an age group corresponds to the mileage of that age group. Values greater than "1" indicate an increased mileage-based risk, values less than "1" indicate a low risk.

3 RESULTS

3.1 Mileage-based accident risk of being involved in an accident

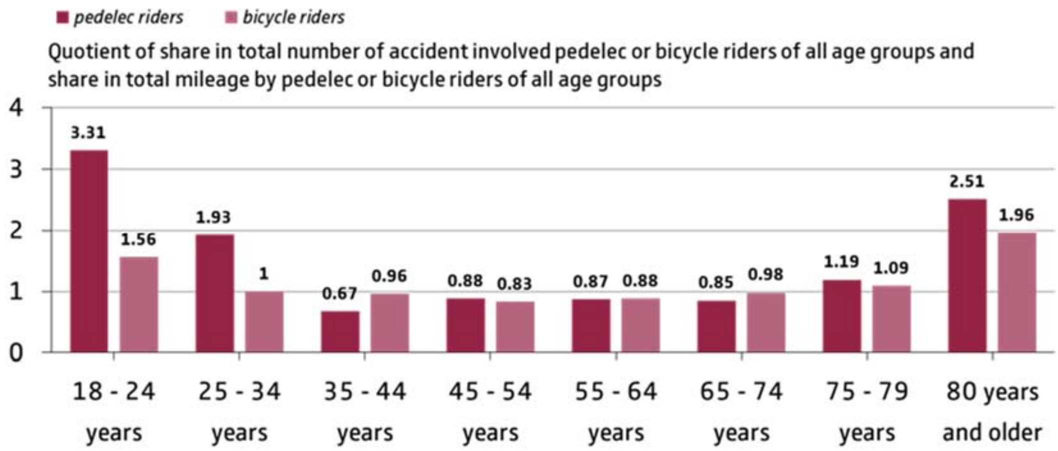

Figure 1: Mileage-based accident risk of being involved in an accident with personal injury for pedelec and bicycle riders of different age groups, year 2017.

As can be seen in Fig. 1, among pedelec riders, riders between the ages of 18 and 24 have the highest mileage-based risk of being involved in an accident with personal injury. For them, the risk is 3.3 times higher than one would expect based on their share in total mileage. The second highest mileage-based risk of being involved in an accident was found for pedelec riders aged 80 and older (quotient: 2.5), the third highest risk was found for pedelec riders aged between 25 and 34 (quotient: 1.9). A slightly increased mileage-based risk can be seen for pedelec riders between 75 and 79 years of age (quotient: 1.2).

Comparing the two types of two-wheelers, and looking at quotients greater than 1, we see a significantly higher risk for pedelec riders than for bicycle riders in the age groups 18 to 24 years old (difference: +1.75) and 25 to 34 years old (difference: +0.93). In the age group 80 years and older there is also a higher risk for pedelec riders than for bicycle riders, although the difference (+0.55) is not as large here as in the other two age groups.

Adult pedelec riders between 35 and 74 years of age do not show an increased mileage-based accident risk of being involved in an accident. There is also no difference in the accident risk compared to bicycle riders of the same age.

The results for the mileage-based accident risk of causing an accident are very similar.

3.2 Mileage-based accident risk of getting seriously injured or killed

Among pedelec riders, riders 80 years and older have the highest mileage-based risk of being seriously injured or killed in an accident. Their risk is 3.2 times higher than one would expect based on their share in total mileage. The second highest mileage-based risk of being seriously injured or killed in an accident was found for pedelec riders between the ages of 18 and 24 (quotient: 1.8), the third highest risk was found for pedelec riders between 75 and 79 years (quotient: 1.4).

Comparing the two types of two-wheelers, and considering quotients greater than 1, there is a significantly higher risk for pedelec riders than for bicycle riders in the age groups 18 to 24 years old (difference: +0.75) and 25 to 34 years old (difference +0.47). In old age, the difference between bicycle riders and pedelec riders is only 0.28 (for riders between 75 and 79 years) and 0.27 (for riders 80 years and older).

Adult pedelec riders between 35 and 74 years of age do not show an increased mileage-based accident risk of being seriously injured or killed in an accident. There is also no difference in the accident risk compared to bicycle riders of the same age.

4 DISCUSSION

For the first time, the mileage-based accident risks for pedelec riders were calculated and compared with those of bicycle riders. An increased mileage-based risk of being involved in an accident or causing an accident was found for younger (18- to 34-year-old) and elderly (over 75-year-old) pedelec riders. Such a pattern is also evident for bicycle riders, but the ratios are especially higher for younger (18- to 34-year-old) pedelec riders than for bicycle riders of the same age. For elderly (75 years and older) pedelec riders, the difference to bicycle riders is smaller. In the younger age groups, riders might be overconfident of their own abilities and/or might be more willing to take risks. It is also possible that younger riders exploit the potential of the pedal assistance to achieve higher speeds more than elderly riders do. Age, in turn, brings about (nonpathological) changes in physical and mental performance. This can lead to difficulties in handling two-wheelers, even at lower speeds. In addition, pedelecs are significantly heavier than normal bicycles due to the technology installed. The mileage-based risk of being involved in an accident or causing an accident is higher for younger and elderly pedelec riders than for cyclists of the same age. A pedelec-specific risk seems to add here.

The mileage-based risk of becoming seriously injured or killed in an accident is increased for pedelec riders and cyclists over 75 years of age. Here, there is not much difference between the types of two-wheelers. It seems that the high physical vulnerability of elderly riders becomes determinant. A clearly higher mileage-based risk of becoming seriously injured or killed in an accident compared to bicycle riders of the same age was found for pedelec riders between 18 and 24 years. This finding is somehow unexpected, and the development here should be further monitored.

5 CONCLUSIONS

Pedelecs are still mostly ridden by elderly people. However, elderly people have a particularly high risk of accidents. Therefore, various measures should be taken (e.g., advice when buying a pedelec, participation in pedelec courses/training, wearing a bicycle helmet). Elderly riders would particularly benefit if the pedal assistance power of the pedelec was more closely linked to their own muscle power.

A new focus is on younger pedelec riders. Although pedelec riders between the ages of 18 and 34 are few in absolute numbers, they have a clearly higher accident risk, in relation to their mileage, than other pedelec riders under the age of 75 or than bicycle riders of the same age. This trend should be monitored further. It is expected that this group will continue to grow.

To further investigate the reasons for the higher pedelec accident risks specific data on the course of the accident, especially the speed at the time of the accident, will be required. In addition, it would also be useful to have up-to-date and representative mobility data, especially on mileage to cover more recent developments.

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Development of German pedelec (and bicycle) accidents between 2012 and 2020

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Keywords: electric bicycle, crashes, accident analysis, e-bike, e-bike safety

1 INTRODUCTION

In the recent years, pedelecs (pedal electric cycles) have seen a massive growth in ridership. In 2013, around 1.3 million e-bikes were on German roads, while in 2020, this number was already at 8.5 million (with about 99% of the e-bikes being pedelecs) [1], [2]. The rapid spread of pedelecs has given rise to concerns for road safety, especially due to the fact that riders of electric bicycles reach higher speeds [3]. Indeed, some studies have reported that pedelec riders suffer from more severe crashes than users of conventional bikes [4], [5]. However, the highly dynamic development in pedelec ownership and use [6] might cast some doubts on the long term validity of investigations of pedelec accidents and their characteristics that have to rely on data collected over shorter periods of time. Therefore, the aim of this study was to investigate pedelec accidents and their characteristics over several years in a longitudinal fashion, and compare them to accidents involving cyclists, to be able to identify trends, and to clarify whether such trends are specific to pedelecs.

2 METHOD

We analysed police reported pedelec and bicycle accidents with personal injury from 2012 till 2020. The dataset consisted of accidents from three federal states of Germany: Brandenburg, Hesse and Saxony. Accidents were included in the analysis if at least one pedelec rider or one cyclist were involved and one of the accident partners was injured.

3 RESULTS

In total, 94.823 injury accidents with the involvement of at least one cyclist or one pedelec rider were found in the dataset. 4,175 of the individuals involved rode a pedelec, 97,647 rode a conventional bicycle. The number of crashed cyclists was quite stable over the years. The number of pedelec riders, however, increased each year, with the 2020 crash number being more than 40 times than the one in 2012.

Table 1: Number of accidents and with the involvement of cyclists and pedelec riders.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Number of accidents	9,916	9,219	10,527	10,135	10,550	10,188	11,401	11,117	11,770	94,823
Bicycle rider	10,592	9,770	11,137	10,531	10,989	10,499	11,652	11,059	11,418	97,647
Pedelec rider	33	119	176	286	290	398	648	887	1,338	4,175

3.1 Sex and age

For both bicycle types, men were more frequently involved in accidents than women throughout the years (total bicycle: 64.3 % men, pedelec: 64.9 % men). Pedelec riders who crashed were about 15 to 20 years older than the conventional cyclists ($F(1, 99692) = 1099.80$, $p < .001$, $\eta^2_p = 0.011$). At the same time, however, the mean age of these pedelec riders has decreased noticeably over time, from 61 years in 2016 to 54 years in 2020 (see Figure 3; $F(8, 99692) = 9.86$, $p < .001$, $\eta^2_p = 0.001$ for the interaction). The ANOVA revealed also a main effect of the time ($F(8, 99692) = 6.45$, $p < .001$, $\eta^2_p = 0.001$), which was driven by the decrease in age of the pedelec riders.

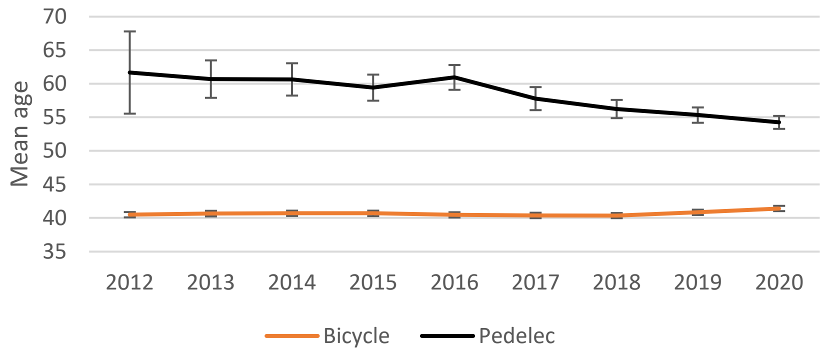

Figure 1: Mean age of the pedelec riders and conventional cyclist from 2012 - 2020.

3.2 Accident location

Most of the accidents occurred in town/village for both bicycle types, however the share was lower for pedelec riders (85.9 %) compared the conventional cyclists (92.2%). In contrast, the proportion of accidents out of town/village were nearly twice as high for the pedelec riders (14.1 %) than for cyclists (7.8 %). The overwhelming number of the accidents occurred on the roadway for both bicycle types (both 84.0 %), followed by bicycle infrastructure (bicycle: 11.8 %; pedelec: 11.0 %). Accidents on the pavement and unpaved paths were rare occurrences for both groups. The relative frequency for pedelec riders crashing while riding downhill (12.2 %) was slightly higher than for conventional cyclists (8.3 %). Cyclists, on the other hand, had a higher proportion of accidents that occurred at intersection and junctions (69 %) than pedelec riders (60.3 %). A longitudinal analysis of this data will be part of the full paper.

3.3 Accident severity

In each year from 2012 till 2020, injury accidents for pedelec riders were more severe than those of conventional cyclists (see Figure 1). The share of fatalities among pedelec riders was more than twice as high as for cyclists in most years. The proportion of seriously injured cyclists remained stable over the years. From 2014 to 2019 the difference between the bicycle types stabilised at around 6 to 7 percentage points. In 2020, however, the gap increased again, with nearly 10 percentage points between the two bicycle types.

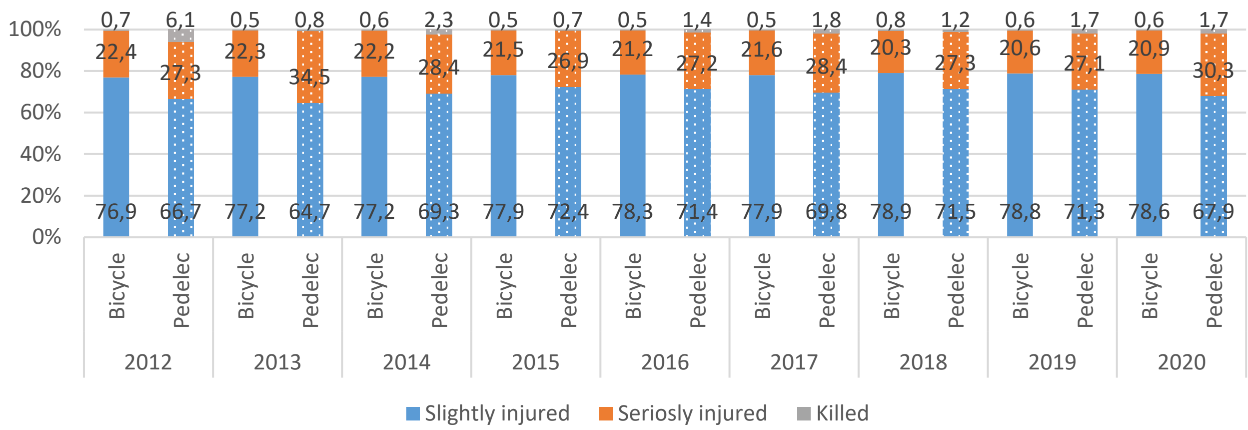

Figure 2: Proportion of accidents per accident severity and bicycle type from 2012 - 2020.

3.4 Accident type and number of accident parties

For both bicycle types, most frequent were accidents by turning into a road or by crossing it, which stayed the number one accident type over the whole period of time (bicycle: 33.3 % - 40.1 %; pedelec: 34.7 % - 41.4 %). Pedelec riders had a noticeably higher proportion of riding accidents (loss of control without other road users having contributed) than conventional cyclists throughout the years (bicycle: 8.9 %-17.2 %; pedelec: 12.1 % - 23.6 %). Accordingly, the number of single accidents was consistently higher for pedelec riders than for conventional cyclists. At the same time, the number of single accidents has risen considerably since 2017 for both bicycle types (2017: bicycle: 12.8 %, pedelec: 16.3 %; 2020: bicycle: 20.9 %; pedelec: 26.8 %).

3.5 Further variables

Among other variables of interest were the time of day the accident occurred, as well as the accident partner. Not surprisingly, cars were the most frequent conflict partners overall, for both bicycle types. Pedelec riders were found to crash at a higher relative frequency before noon (9.00 till 11.59) and at lunchtime (12.00 till 14.59) compared to cyclists, while cyclists' accidents occurred more frequently in the morning hours between 5.00 and 8.59.

4 DISCUSSION

The aim of this study was to shed some light on the characteristics of pedelec accidents over a longer period of time. Overall, many of the analysed variables showed a certain degree of temporal stability, with differences as well as similarities between accident characteristics of the two bicycle types staying quite consistent over the years. Just like the rider population in general, pedelec riders that crashed tended to be older than cyclists, although their mean age declined slightly in recent years, which reflects changes in the user group. As expected, we also found a higher accident severity for pedelec riders compared to cyclists, which is comparable to other studies [5], [7]. Especially in 2020, the difference was quite pronounced, which might be explained by different usage patterns during the COVID-19 pandemic compared to previous years. Overall however, the difference was rather consistent over time. In line with the findings of other studies a higher number of single respectively riding accidents for the pedelec riders compared to the conventional cyclists was detected [4].

While of considerable size, the dataset is not without limitations. Many bicycle and pedelec accidents go unreported, especially single-vehicle accidents and those of low severity [6], resulting in a potential bias. In addition, a measure of exposure, e.g., distance travelled, is missing, since no such information is available on a year-by-year basis in Germany. Still, a combination with travel data from one of the regular household surveys might be considered to at least get a general understanding how the trends in crashes might relate to developments in bicycle and pedelec use.

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Data for evidence: Defining, collecting and analysing specific data from pedelec accidents as an example of individual, targeted road safety work for new forms of mobility

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Keywords: pedelec, electric bicycle, accident analysis, mixed method approach, accident data extraction.

1 INTRODUCTION

Cycling, as one of the oldest forms of mobility, is currently experiencing a renaissance. It supports active mobility and can have a positive influence on public health, the environment, climate and the traffic situation. Pedelecs (bicycles with an electric motor supporting the user up to a speed of 25 kmph) represent a new form of active mobility and are currently enjoying great popularity as they have the same benefits compared to conventional bicycles and, in addition, make cycling accessible to new user groups. With the growing number of pedelecs, however, potential for conflict also increases. Unfortunately, the majority of accidents cannot yet be analysed accordingly, as pedelec-specific characteristics are missing from the accident data. This fact in itself has already been proven as a barrier.

Most accident studies focusing on pedelecs are based on police data from standardised accident forms [e.g. 1, 2, 3, 4]. Their findings can be summarised in the following key statements: Accidents with pedelecs are less frequent but more severe than those with conventional bicycles. For both, accidents on urban roads dominate, but pedelec accidents occur significantly more often on rural roads than conventional bicycle accidents. And: injured pedelec users, especially those fatally injured, are on average significantly older than injured users of conventional bicycles.

But, standardised accident forms were initially designed for accidents with double-track motor vehicles, in particular passenger cars. Accidents with bicycles (especially pedelecs), are difficult to categorise with this systematic as important information is missing. For example, “falling on ground” is not an accident category as cars normally won’t do so, but for pedelec accidents, this information is fundamental.

This acts as a barrier as bicycle-specific causes of accidents cannot be analysed. However, accident statistics are the most important basis for evidence-based measures in road safety work.

The aim of this paper is therefore to identify and categorise pedelec-specific accident characteristics and to evaluate pedelec accidents on the basis of these characteristics to identify frequent and severe accident constellations.

2 DATA AND METHODS

To get more detailed information on these accidents, I had the opportunity to evaluate not only the official statistics, but also accident text descriptions of police officers written on site. Those were provided to us by the 16 German polices as a special data set. It included 6,253 accidents involving pedelecs from the years 2016 and 2017, covering 68 % of all pedelec accidents of that period. The new categories were defined on the basis of the breakdown of the literature analysis and are thus intended to cover all pedelec-specific aspects of accidents. After the screening, these categories were evaluated and further subdivided or summarised as required. The literature analysis showed that pedelec single accidents are fundamentally different from accidents involving a pedelec and further road users. Therefore, single accidents were excluded from this data set and investigated in a separate project (see [5]). In addition, accidents without injured pedelec drivers were excluded as the focus of the study was to prevent (severe) injuries of pedelec users. This led to a data set of 4,196 accidents.

The resulting categories were again checked for plausibility and completeness. Subsequently, all 4,196 accident text descriptions were read and the respective accidents assigned to one or more categories. In contrast

to the official definition, the new definitions are interpreted more broadly. Although even in the official statistics, presumptions of the police officers would suffice as reasons for some variables (e.g. causes of the accident), in practice, only officially verifiable evidence is usually categorised here. Obvious connections are often not considered. In contrast, the classification in the new categories was rather based on the long-term expertise of the researchers regarding relevant accident factors [5]. In total, 13 categories were defined, they are displayed in Table 1. Most of categories even had subcategories (for example, the category “distance too short” has the subcategories “pedelec kept too short distance” and “opponent kept too short distance”) and some categories included several variables (category 13 “special junctions” included “accidents at roundabouts” and “accidents at “property entrances”). Category 1 has a special point of view as it does not describe accident causes, but the part of the road used by the pedelec prior to the accident, distinguishing even between different kinds of cycle lanes (on or next to lane, shared with pedestrians, etc.).
To identify frequent and severe accident constellations, all accidents and their new categorisations as well as additional information (from the standardised accident collection) were brought together in one data base and then analysed using multilayer cross tabulation analysis.

3 RESULTS

Table 1 shows the result of the qualitative analysis: 13 new, pedelec specific accident categories could be identified and accidents could be categorised to them subsequently.
The table also shows the result of the basic quantitative analysis: The most frequent conflicts are those in which the pedelec is overlooked by a motor vehicle or bicycle (58.4 % of all accidents) (the pedelec usually approaches from the right), in which the parties involved (mostly opponents) disregard the right of way (31.3 %) or in which the parties involved (more often the opponents) maintain too short safety distance or misjudge the space required (24.5 %).
Additional analysis showed, that in about three quarters of all accidents, the pedelec is not the main perpetrator. In accidents with pedelec as the main perpetrator, however, the severity of the accident is significantly higher.
The highest accident severity was found in conflicts when pedelec violated red light (460), pedelec users gave poor (or no) hand signal when changing direction (444), pedelec disregarded the right of way (430) or pedelec got stuck on an obstacle or touched it (429).
In almost half (45.9%) of all accidents, it was noted that the pedelec was on a pedestrian and/or cycle facility (GRVA), and the accident severity was significantly lower (189) than in accidents on the lane without cycle facilities (249). The proportion is thus significantly higher than in the official statistics, where it was only noted in 18% of accidents that the pedelec was on a cycle facility.
In the analyses, some findings were striking and recurring. These accumulations point to further specifics of pedelec accidents. Therefore, in the last step, typical constellations were identified and examined in detail as scenarios. For this purpose, the new categories were analysed with the standardised accident types. The following constellations could be identified:

Table 1: New categories

Accidents with personal injury involving two or more road users (including at least one pedelec) in the period 2016-2017

Category	variables, subvariables	Number of accidents	number of pedelec users injured… total	fatally	severely	slightly	accident severity*
0	total	4.196	3.857	52	877	2.928	221
1	Traffic area used by pedelec before collision:						
	Walking/cycling facility (GRVA)	1.919	1.756	14	348	1.394	189
	GRVA structurally separated: pavement	220	196	3	32	161	159
	GRVA structurally separated: cycle path	1.042	956	7	185	764	184
	GRVA struc. sep.: shared foot- & cycle path	439	397	1	90	306	207
	GRVA on carriageway: cycle lane	218	207	3	41	163	202
	Road lane (without cycling facility)	2.277	2.101	38	529	1.534	249
	Addition: on cycle facility in wrong direction	282	257	1	37	219	135
	Addition: GRVA (was free for both directions)	498	464	4	86	374	181
2	Distance too short**	1.028	845	7	220	618	221
	Pedelec	470	363	1	108	254	232
	Opponent	683	577	6	129	442	198
3	Pedelec driving error: stuck/touched…	306	248	2	64	182	216
	Motor vehicle	82	78	1	19	58	244
	Bicycle/Pedelec	166	128	0	33	95	199
	Pedestrian	44	28	1	6	21	159
	Obstacle/other	14	14	0	6	8	429
4	Conflict with parked motor vehicle**	260	252	0	44	208	169
	Dooring	132	129	0	24	105	182
	Parking in / out of a motor vehicle	110	107	0	15	92	136
	Conflict with motor vehicles on cycle paths	26	24	0	5	19	192
5	Violating red light**	78	74	1	29	44	385
	pedelec	50	46	0	23	23	460
	opponent	32	31	1	7	23	250
6	Disregarded right of way	1.313	1.253	18	299	936	241
	Pedelec	286	269	16	107	146	430
	opponent	1.027	984	2	192	790	189
7	Conflict with animals	62	58	0	18	40	290
8	Motor vehicle/bicycle overlooks P25 - P25 from ...	2.451	2.367	17	424	1.926	180
	left	518	503	4	104	395	208
	right	741	715	5	119	591	167
	rear right (blind spot)	293	286	3	57	226	205
	rear left (blind spot)	178	171	0	28	143	157
	Opposite direction	464	443	3	82	358	183
	Direction unclear	257	249	2	34	213	140
9	Carelessness of the pedelec**	377	330	7	120	203	337
	Overlooked	198	171	4	70	97	374
	Mobile phone	3	2	0	0	2	.
	Others	235	210	6	65	139	302
10	Fall without collision**	354	336	2	44	290	130
	Evasion	152	141	1	21	119	145
	Brakes/Braking	213	206	1	23	182	113
11	Poor hand signal	81	69	3	33	33	444
12	Cut curve**	132	120	1	29	90	227
	Pedelec	45	40	0	14	26	311
	Opponent	89	80	1	15	64	180
	Cut after overtaking	124	116	3	29	84	258
	Pedelec	18	12	0	4	8	222
	Opponent	106	104	3	25	76	264
	Pedelec lane change	76	70	2	19	49	276
	Pedelec lane crossing	76	73	5	25	43	395
	Motor vehicle crossing cycle lane	5	5	0	2	3	.
13	Roundabout	130	125	1	30	94	238
	Property entrance (garage driveway, etc.)	596	576	4	83	489	146

*Accident severity: Fatalities and serious injuries of pedelec users per 1,000 accidents involving a pedelec. No calculation of accident severity if less

** Multiple answers possible

Constellation “accidents at junctions”: a) Criterion of right of way/priority: In almost half of the accidents at junctions, the parties involved disregard right of way or priority, mostly not the pedelec but the opponents. b) Criterion of overlooking: pedelecs are often overlooked, mostly by passenger cars and mostly when the pedelec is approaching from the right. The severity of accidents is generally below average, but high if a vehicle overlooks a pedelec approaching from the rear right or left. This can be seen as an indication of the problem of the "blind spot", especially for lorries. c) Criterion roundabout: Accidents at roundabouts are rare. The severity of accidents was above average, especially when the pedelec was on the main lane. d) Criterion red light violation: Accidents due to red light violation are rare but severe.

Constellation “Pedestrian”: Accidents between pedelecs and pedestrians are rare and with below-average accident severity (for pedelec users). Nevertheless, there is potential for conflict due to the road space that is often used jointly (often against the rules).

Constellation “parking/stopping vehicles”: Of the three subcategories of conflicts with parking/stopping vehicles, conflicts of with a suddenly opening vehicle door (“dooring”) were the most frequent; these were particularly severe when the pedelec approached from the rear right and/or when there was a fall without collision, for example due to an evasive manoeuvre. Conflicts with motor vehicles in cycling lanes had the highest accident severity of this constellation, mostly when pedelec got stuck on or touched a motor vehicle.

Constellation “Longitudinal traffic”: Most accidents in longitudinal traffic occurred due to insufficient safety distance. Serious accidents often occur when a bicycle cuts a P25 while overtaking.

4 DISCUSSION AND CONCLUSIONS

Pedelecs are still a new type of vehicle and specific accident analysis is still missing as standardised accident statistics do not consider pedelec specific accident causes. To analyse this problem, a mixed method approach was used and 4,196 accident descriptions were read and analysed. The qualitative analysis gave evidence of the existence of pedelec specific accident causes and made it possible to created 13 new pedelec specific accident cause categories (with addition subcategories) that are not available in the standardised accident report. Initial results of the quantitative analysis show that most frequent conflicts occur when pedelecs were not seen by other road users. With the help of the new categories, it was possible to look at this problem in more detail. For example, pedelecs are often not seen because they did give no / poor hand signal when turning. Additional, pedelec accidents often happen because of violation of right of way or too short distance, both also often happening due to overlooking the pedelec. Hence, making the pedelec more visible seems to be a priority. On the other hand, highest accident severities were found in connection with pedelec user’s mistakes (violating red light, poor hand signal, disregarding right of way or pedelec got stuck on an obstacle). Therefore, a second priority appears to be raising awareness among pedelec users. Finally, accidents on cycle facilities had significantly lower severities, which highlights the expansion of safe cycling infrastructure as the third priority. In addition, four frequent constellations of pedelec accidents could be identified (at junctions; with pedestrians; with parking/stopping vehicles; in longitudinal traffic) which can be seen as focal points for the implementation of the priorities presented above. The results provide pedelec specific information that function as a basis for analysis on the need for new requirements on road safety work.

5 ACKNOWLEDGEMENTS

I would like to take this opportunity to express my thanks to Nadja Faerber and Martin Pöppel-Decker from BASt who requested/collected the data and read and categorised all 4,196 Pedelec 25 accidents.

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Risk perception and differences in self-reported cycling behavior between electric- and conventional-bike riders in Denmark

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Keywords: cycling behavior, risk perception, e-bikes.

1 INTRODUCTION

Electric bikes can contribute to the decrease of emissions and present a carbon-positive alternative to gas-powered forms of motorized transport [1][2]. Hence, the fact that both conventional and e-bike use have increased considerably during the Covid-19 pandemic can be considered as a positive development [3]. At the same time, studies find that e-bike riders are traveling with higher speeds [4], and report new types of safety incidents, that they did not experience during conventional cycling [5]. Risk related behavior of e-bike and c-bike riders has frequently been linked to crash-risk and injury severity [6][7]. But little research has been conducted on the comparison of self-reported risk related behavior between e-bike and conventional bike (c-bike) riders. Hence, in this study, the self-reported risk-related behavior of c-bike and e-bike riders was investigated.

2 METHOD

2.1 Sample

A total of 557 cyclists were recruited as a convenience sample through social media and a newsletter from the Danish cyclist federation for an online study on their behavior during everyday cycling. 316 participants were female (57%), and 241 male (43%). Mean age of participants was $m= 47$ ($SD=14$). With 87% ($n=483$), most respondents used a c-bike as their main form of transportation, while 13% ($n=74$) used an e-bike.

2.2 Instruments

In this study, the Cycling Behavior Questionnaire (CBQ) was used to assess safety related behavior of e-bike and c-bike users [8]. It consists of 29 items which assess the frequency of cycling behavior on a five-point scale (0=never; 1=hardly ever; 2=sometimes; 3=frequently; 4=almost always). The CBQ items map to three factors, *violations* (e.g. "Going against the direction of traffic (wrong way)"), *errors* (e.g. "Fail to notice the presence of pedestrians crossing when turning"), and *positive behavior* (e.g. "I usually keep a safe distance from other cyclists or vehicles."). In addition, sociodemographic items, as well as questions on general cycle use (type of bike mainly used (c-bike/e-bike), frequency, usual trip length, purpose) were added. Single items on risk-perception and traffic law regulation were presented [9].

2.3 Analysis

First, sample characteristics (e.g., age, gender, trip length) for c-bike and e-bike riders are compared using $\chi 2$-tests and *Aspin-Welch-Satterthwaite t-test*. To investigate possible latent cycling behavior, relating to either e-bike or c-bike use, a factor analysis is performed on the three scales of the CBQ. Analyses were performed with Varimax rotation and confirmed the three different scales of the CBQ: *Violations, Errors*, and *Positive behavior*. Cronbach's alpha was 0.70. All items have factor loadings above 0.43 and explained 42% of the variance. Finally, a structural equation model (SEM) is employed to identify latent cycling behavior and their relation to riders' demographic features, trip length, purpose and self-assessed risk perception and regulation knowledge to e-bike use.

3 RESULTS

Personal and trip characteristics for all respondents are presented in Table 1. It can be observed that e-bike users are more likely to be female and live in a smaller city, with less than 50,000 inhabitants. We also find e-bike users to be more likely to have retired but find no significant difference between age groups for e-bike and c-bike users (age of riders: e-bike, m=49, SD=14.0; c-bike, m=47, SD=14.5). No significant differences were found for number of hours biking during a normal week or duration of the most frequent trip. However, results show c-bike users to more often (45%, n=217) use their bike for exercise than e-bike users (31%, n=23).

Table 1: A comparison of person and trip characteristics between e-bike and c-bike users

		e-bike		**c-bike**			**X^2-test, p-value**
Variable	**category**	**Number**	**%**	**Number**	**%**	**total**	
Gender	Male	22	9	220	91	242	
	Female	52	16	264	84	316	**<0.01**
Number of inhabitants in city	less than 50,000	27	21	102	79	129	
	between 50,000 and 200,000	20	11	163	89	183	
	Above 200,000	27	11	218	89	245	**0.01**
Occupation	Working (self-employed and others)	53	13	356	87	409	
	Retired	13	23	43	77	56	
	Unemployed, student and other	8	11	84	91	92	**0.04**
Bike use in a (normal) week	Less than 3 hours	16	14	96	86	112	
	between 3 and 5 hours	28	14	178	86	206	
	between 6 and 9 hours	20	14	127	86	148	
	10 hours or more	10	11	81	89	91	0.91
Time for most frequent trip	Less than 20 minutes	11	8	119	92	130	
	20-30 minutes	30	13	200	87	230	
	31-59 minutes	25	20	102	80	127	
	more than 60 minutes	8	11	62	89	70	0.06

Regarding cycling behavior assesses with the CBQ, we only found significant differences between e-bike and c-bike riders in the mean for the factor *Positive behaviors* (p=0.02) where a higher mean was found for e-bike users. For the factors *Traffic violations* (p=0.07) and *Errors* (p=0.92) we found no significant difference. For risk perception e-bike users reported a higher awareness of risks related to headphone or general mobile phone use while cycling (p<0.01) and for consequences of being involved in a traffic crash (p=0.04). Regarding traffic regulation e-bike users reported higher knowledge of traffic rules for other vehicles (p=0.01), knowledge of cycling safety regulations (p=0.04), and higher recognition of areas prohibited to traffic or bicycle parking (p=0.02).

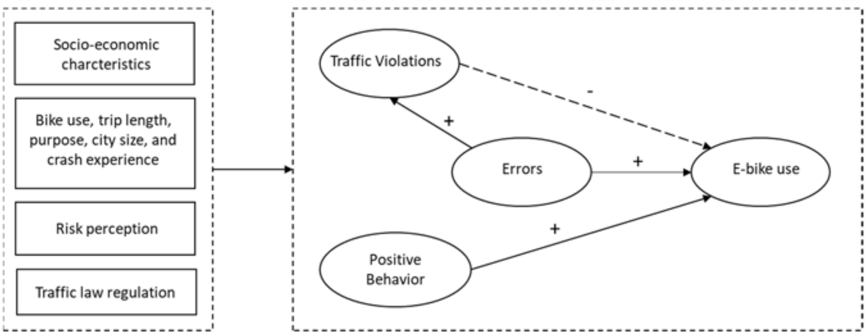

Figure 1: Structural Equation Model for study variables related to e-bike use.

The results of the structural equation model revealed e-bike use to be directly and positively related to *Errors* and *Positive Behavior* and negatively related to *Traffic Violations,* which are positively related to *Errors*. The most relevant factor for mainly cycling on an e-bike is *Positive Behavior* (Figure 1). We further find that the use of an e-bike is positively related to a higher reported awareness of increased crash risk in cities and when using headphones or mobile phone while cycling. A positive relation with e-bike use is also found for females, smaller cities (number of inhabitants below 50,000) and occupation.

4 DISCUSSION AND CONCLUSION

The results of this study revealed that female, retired people, and cyclist living outside the large cities were more likely to use an e-bike as main transport mode compared to a c-bike. Likewise, we found that using an e-bike as main transport mode is positively related to a higher crash risk awareness which may make e-bike riders more careful in traffic. This could be due to an increased focus in social media and news about the high crash risk when cycling on an e-bike, which is also supported by research on e-bike safety [5][6].

Regarding the cycling behavior assessed with the CBQ, we found that *Traffic Violations* were negatively related to the use of e-bikes which indicates that e-bike users are more careful in traffic than c-bike users**.** At the same time, the data suggests that a higher frequency of self-reported *Errors* is positively related to *Traffic Violations* for e-bike riders. This can indicate that cyclists' susceptibility to make errors (unconsciously), can contribute to traffic rule violations. *Positive Behavior* when cycling and a higher reporting of *Errors* were found to be positively related to the use of e-bikes. This could be interpreted as e-bike riders making more errors in traffic but could also indicate that they are just more aware of the errors they make than c-bike users (no causal inference can be derived from our study design). In general, our data suggests that e-bike riders have a safety-positive behavior when cycling and higher knowledge of the traffic rules compared to c-bike users.

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E-cargo bicycles: on cycle path of carriageway?

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Keywords: light electric vehicles, place on the road, heavy e-cargo bike

1 INTRODUCTION

To ensure that e-cargo bicycles and other light electric vehicles are technically safe and used safely, an Approval Framework for Light Electric Vehicles (LEV framework) is being developed in The Netherlands. The LEV Framework also governs the place on the road of LEVs. Sessions with road authorities in the preparation of the LEV framework in 2020 showed that some road authorities were concerned about heavy e-cargo bicycles on bicycle paths because of their size and the mass difference with cyclists [1]. For this reason, it was investigated what the most suitable traffic rules are for the place on the road of heavy e-cargo bicycles for transporting goods or children with a maximum construction speed of 25 km/h: the cycle path, the carriageway or, depending on the traffic situation, a tailor-made solution in between.

2 APPROACH

This abstract is based on Rijkswaterstaat's Background Report Place on the Road of the electric cargo bike [2]. This report describes options for legally regulating the place on the road, contains statistics on the width of bicycle paths in the Netherlands and literature to determine the social effects of the options. The report also discusses, for example, the relationship with EU Regulation 168/2013. Under the supervision of the TRIDÉE research agency, the options were discussed in working sessions with knowledge institutions, enforcers, road authorities, courier companies and social organizations.

3 OPTIONS PLACE ON THE ROAD

In this study, options are compared with the zero option, in which the cycle path remains the starting point for the place of the heavy e-cargo bike on the road. Other options restrict the ability to use cycle paths and require the use of the carriageway. It is estimated that when the LEV Framework comes into effect, there will be approximately 10,000 heavy e-cargo bicycles.

The following options for the place on the road are considered:

- Heavy e-cargo bike follows the rules for cyclists (zero option)
- Heavy e-cargo bikes with greater mass mandatory on the carriageway
- Heavy e-cargo bikes with greater width mandatory on the carriageway
- Customization at the municipal level linked to slow mopeds on the carriageway: existing option in The Netherlands whereby municipalities can require 25 km/h mopeds, and in this option also e-cargo bikes, to travel on the carriageway
- Heavy e-cargo bikes mandatory on the carriageway when it has a speed limit of 30 km/h
- Advisory bicycle path at 30 km/h

4 CONCLUSIONS

The main conclusions of the study are:

- The most important preconditions for traffic rules are that they are understandable for all road users and enforceable. These preconditions come under pressure when heavy e-cargo bicycles are no longer allowed on the cycle path, because the number of heavy e-cargo bicycles is still small (approximately 10,000 vehicles in 2022 [3]) and they are visually difficult to distinguish from light e-cargo bicycles that must stay on the cycle path..
- Safe use is an important motivation for the LEV framework. Overall, the heavy e-cargo bike on the cycle path is the most favourable for road safety. At speeds of up to approx. 30 km/h, vehicles with large differences in mass can be safely mixed. With speeds of up to 25 km/h for the e-cargo bike, the speed difference with motorized traffic on a 50 km/h carriageway is too great while the speed on the cycle paths will remain under 30 km/h.
- On 30 km/h roads with separate cycle paths where the limit is properly observed, the heavy e-cargo bike could travel safely on the roadway. As indicated in the first conclusion, this would not be understandable and enforceable. Moreover, the length of 30 km/h roads with separate cycle paths is small and it appears that the limit is frequently exceeded on these roads.

DISCUSSION

Understandability and enforceability of traffic rules are preconditions and necessary to achieve the intended effect. Given the aim of the LEV Framework to enable safe use, road safety is a crucial aspect for assessing rules. The work sessions showed that road authorities and social organizations consider the cycling climate important. The cycling climate benefits from keeping large and heavy vehicles such as e-cargo bikes off the cycle path. On the other hand, environmentally friendly transport with, among other things, LEVs is valued by stakeholders, of which the use is most stimulated by allowing the use of bicycle paths. With these considerations, it was decided to formulate the main conclusions on comprehensibility, enforceability and road safety.

As yet, little empirical research on the effects of place on the road of the e-cargo bike is available. Monitoring of the LEV framework is planned and can help build knowledge.

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Development and Validation of a Remote-Controlled Test Platform for Bicycle Dynamics

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Keywords: bicycle, test platform, remote controlled, stabilizing.

1 INTRODUCTION

Through the electrification of bicycles, the implementation of new active and passive safety systems becomes possible. Examples for such systems are bicycle ABS [1], TU Delft – Fall Prevention Bicycle [2], Bosch Help Connect (eCall System for bicycles) [3], airbag helmets [4] and many others. One of the main difficulties in developing and testing such safety systems is, that test riders should not be exposed to high risks when testing early prototypes. Thus, an automated or remote-controlled test platform for the analysis of bicycle dynamics and for testing of newly developed safety systems could boost the development of such systems and make it safer.

The main difficulty when developing such a test platform, which has been addressed in this work, is stabilizing it at low speeds (1.5 m/s – 4.5 m/s) and being capable of tracking a desired yaw rate, only using a steer actuator. In the following, the development of such a test platform is described and first experimental results are presented.

2 MODEL

While for simulations, one can use quite complex nonlinear bicycle models, which are mostly based on the Carvallo-Whipple model [5], [6], for controller design and analysis much simpler models are necessary. Such a simplified nonlinear model was introduced by Getz [7] and is used for controller design in this work. In this simplified model, the four bodies of the Carvallo-Whipple Model are reduced to two bodies, tire radiuses are set to zero, inertias are neglected and steer rate and roll torque are used as inputs for the lateral dynamics (see Figure 1). After linearizing around the origin and setting the roll torque to zero since it is not needed for controller design, the model equations are given as

$$\begin{pmatrix} \dot{\varphi} \\ \ddot{\varphi} \\ \dot{\delta} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 \\ -\frac{g}{z} & 0 & \frac{v^2}{l\,z} \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \varphi \\ \dot{\varphi} \\ \delta \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{x\,v}{l\,z} \\ 1 \end{pmatrix} u_{\delta}. \tag{1}$$

The states of the systems are roll angle φ, roll rate $\dot{\varphi}$ and steer angle δ and the control input is the steer rate u_{δ}. For the parametrization of the model, only four bicycle parameters are needed, namely the wheelbase l, the x- and z-position of the center of gravity and the (constant) velocity v. For small angles, the yaw rate $\dot{\psi}$ of the bicycle can be approximated by

$$\dot{\psi} = \delta\, v/l. \tag{2}$$

In the simplified model, many properties of the full model are no longer depicted (for example self-stability in a certain speed range), but it still includes the basic bicycle dynamics which are necessary for controller design.

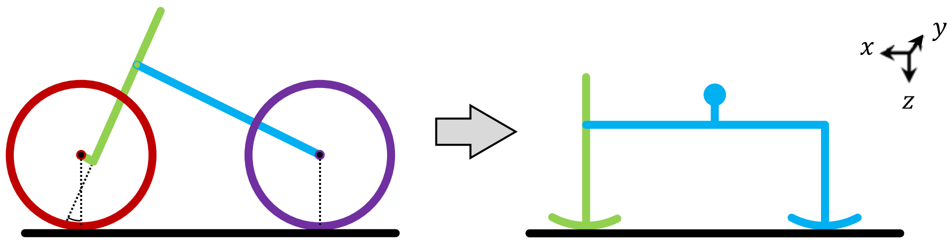

Figure 1: *Reduction of the four-body model to the simplified two-body model*

3 CONTROLLER

Due to the simplifications, on the bicycle model, it is necessary, to design a controller, that has some robustness properties. There are different options, but because of its simple design and simple implementation, an LQR state feedback controller is chosen.

Since the bicycle shall not only be stabilized, but also should follow a reference yaw rate $\dot{\psi}_{\text{ref}}$, it is necessary to add some feedback of the (integrated) yaw rate tracking error. Hence, the state vector is augmented by the integrated yaw rate tracking error ξ. The augmented system is given as

$$\begin{pmatrix} \dot{\varphi} \\ \ddot{\varphi} \\ \dot{\delta} \\ \dot{\xi} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -\frac{g}{z} & 0 & \frac{v^2}{l\,z} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{v}{l} & 0 \end{pmatrix} \begin{pmatrix} \varphi \\ \dot{\varphi} \\ \delta \\ \xi \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{x\,v}{l\,z} \\ 1 \\ 0 \end{pmatrix} u_{\dot{\delta}}. \tag{3}$$

The Complete control loop including the yaw rate tracking error feedback is shown in Figure 2. The control gains are speed dependent and are calculated using LQR control theory.

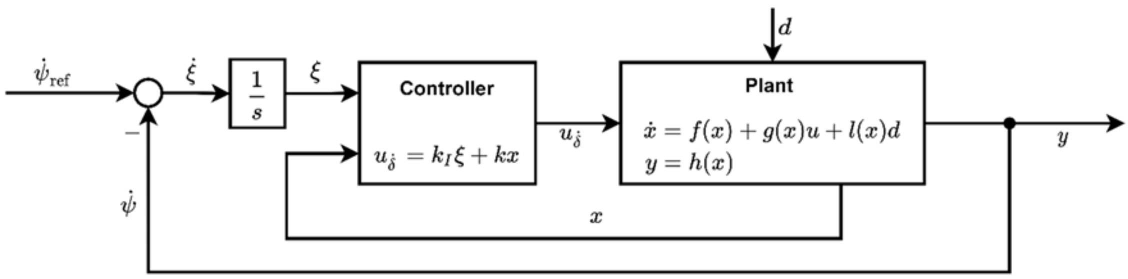

Figure 2: *Control loop of the augmented system*

4 SIMULATIONS AND EXPERIMENTAL RESULTS

Simulations of the proposed control strategy have been made using a modified version of the full bicycle model to allow for steer rate inputs. Additionally, the simulation model includes sensor models and a state estimator to recover the full state vector from the sensor signals. Since simulations show similar results to the experiments, only experimental results of the following two riding scenarios at a constant velocity of $v = 2.5\ \text{m/s}$ are presented in this abstract:

1. Straight motion with pulse-like disturbance at $t_1 = 6\text{s}$ and $t_2 = 12.6\text{s}$.
2. Straight motion with a turn command ($\dot{\psi}_{\text{ref}} = 0.5\text{rad/s}$) at $t_1 = 8\text{s}$.

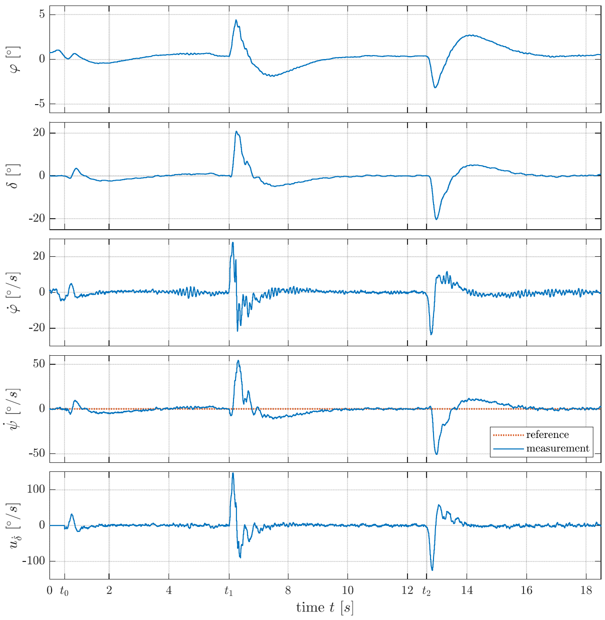

***Figure 3:** Experimental results of driving scenario 1*

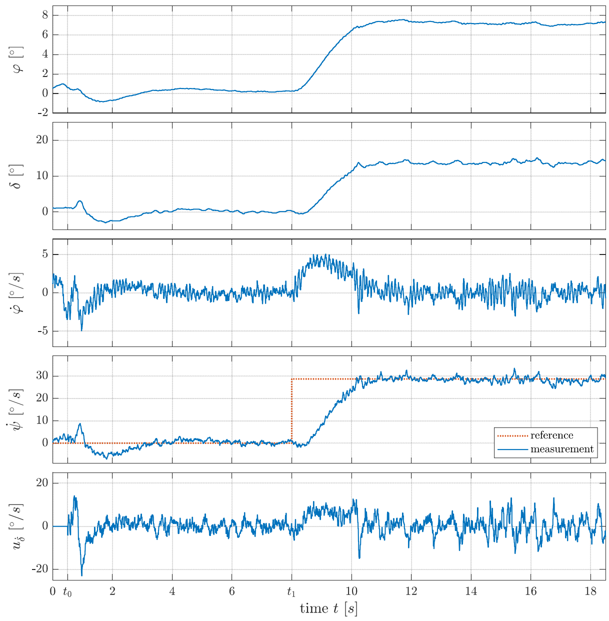

***Figure 4:** Experimental results of driving scenario 2*

The results of the experiments can be seen in Figure 3 and Figure 4. Both measurements start with a part, in which the bicycle is accelerated to the desired speed and in which the lateral dynamics controller is not yet active. As soon as the bicycle reaches the desired speed (at time t_0), the controller is activated and stabilizes the bicycle. The first measurement shows that the bicycle can track a straight line and quickly recovers from disturbances. In the second measurement, tracking a reference yaw rate is demonstrated. It can be observed that the bicycle is again stabilized and follows the desired yaw rate well.

5 CONCLUSION

Development of a remote-controlled bicycle test platform will help developing new safety systems. Our work lays the foundation for building such a platform by providing a method for simultaneously stabilizing a bicycle and tracking a desired yaw rate using a steer actuator. By using a very simple model and by using steer rate as a control input, the stabilization system can be easily adapted to various bicycles (only few parameters need to be known). On the other hand, due to the use of the steer rate as a control input, the reactions to disturbances and setpoint changes (of the yaw rate) are somewhat slow and the bike cannot be used to investigate disturbances to the steering.

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Modeling the Braking Behavior of Micro-Mobility Vehicles

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Keywords: e-scooters, field trials, advanced driving assistance systems, pedelect.

1 INTRODUCTION

According to the community database on accidents on the roads in Europe, 2035 cyclist fatalities happened in Europe in 2019 [5]. In Sweden, 10440 bicycle crashes were reported in the Swedish Traffic Accident Data Acquisition database during 2019, and 30% of the cyclist fatalities were in car-to-cyclist rear-end crashes [6]. Nowadays, new micromobility vehicles (MMVs), for example, e-scooters, and Segways, are becoming more popular. Unlike traditional bicycles, these new MMVs usually have novel designs in appearance, kinematics, operation method, and power source (e.g., electricity-driven/assisted), which bring new hazards to traditional road users [1, 4]. Thus, it is essential to understand and quantify the behavior of the new MMV users to improve road safety.

Advanced driving assistance systems (ADAS) are proven to reduce road fatalities and increase road safety efficiently. ADAS need to know the behavior of road users to predict their intention to avoid crashes. From 2023, the European New Car Assessment Programme (Euro NCAP) will include new car-to-cyclist scenarios to test the capability of the new ADAS, which may also include other MMVs in the future. In ADAS threat assessment studies, maneuver jerks can be used as unique parameters to describe the required corrections for the driver to reach the goal [7]. However, state-of-the-art commercial ADAS make limited use of constant jerk or deceleration from the modeling of drivers and other road users. This study presents new models that describe the longitudinal velocity, deceleration, and jerk of different MMVs in braking events, typical of a rear-end collision-avoidance scenario. The proposed models are computationally efficient and can support ADAS development and its safety assessment (e.g., counterfactual simulations [2]).

2 METHODS

This study analyzed the field data collected from 34 participants who rode a bike (with and without electrical assistance), an e-scooter, and a Segway and performed comfort and harsh braking maneuvers. Each vehicle was equipped with a data logger composed of a Raspberry Pi single-board computer, an inertial measurement unit, a potentiometer, and a GPS module. In addition, a LIDAR mounted near the braking location recorded the velocity and position of the rider. An arctangent function was used as a smooth function to fit the velocity data obtained combining the IMU signals with the information from the LIDAR. A smooth function has all derivatives continuous, which makes it particularly appropriate for dynamic control and approximation [10]. The first derivative of velocity (deceleration) and the second derivative (jerk) were calculated analytically from the data collected in the experiment.

For each participant, 12 fittings were performed over the velocity data: four vehicles (bike, e-bike, e-scooter, and Segway) and three braking maneuvers (comfortable, harsh, and unexpected harsh braking). Then, the velocity was fitted with the function in Equation 1.

$$V = a \cdot \arctan(b \cdot x + c) + d \qquad (1)$$

In Equation 1, ***a***, ***b***, ***c***, and ***d*** are the four coefficients that are produced by the non-linear data-fitting method ***lsqnonlin*** in MATLAB. The deceleration of the vehicle can be obtained by differentiating Equation 1 and is presented in Equation 2.

$$Deceleration = \frac{a \cdot b}{(b \cdot x + c)^2 + 1} \quad (2)$$

By differentiating Equation 2, jerk was calculated (Eq. 3).

$$Jerk = -\frac{2 \cdot a \cdot b \cdot (b \cdot x + c)}{((b \cdot x + c)^2 + 1)^2} \quad (3)$$

3 RESULTS

Figure 1 shows the fitted velocity, deceleration, and jerk for one participant during comfort braking with the e-bike. Fitting the vehicle velocity with the arctangent function demonstrated a high goodness-of-fit (an average R-squared value of 97.41%). In our previous work [3] the velocity was fitted with linear regression. The derivation of the fitted velocity curve produces similar results for maximum deceleration compared with linear regression, and the latter has a better goodness-of-fit, around 98% on average.

During all three braking tasks, the participants were able to brake with larger decelerations when riding e-bike and bike compared to when riding e-scooter and Segway. The braking performances of the Segways were poorer even if the maximum speed is limited to 15 km/h (lower than bike, e-bike, and e-scooter). The average decelerations of all vehicles were significantly larger in the harsh braking tasks than the decelerations in the comfort braking tasks, and the decelerations were slightly larger in the unexpected harsh braking task than in the planned harsh braking task. As for the jerks, the non-assisted bike achieved a larger jerk than other three electric vehicles during comfort and unplanned harsh braking. The e-scooter and Segway had significant smaller jerks than the bikes, the minimum jerk of the Segway was about a half of the minimum jerk of e-scooter, in average. Similarly to the decelerations, the jerks in the harsh braking tasks were larger than the jerk in comfort braking. Further, during unplanned harsh braking the jerk was larger than that in the planned harsh braking.

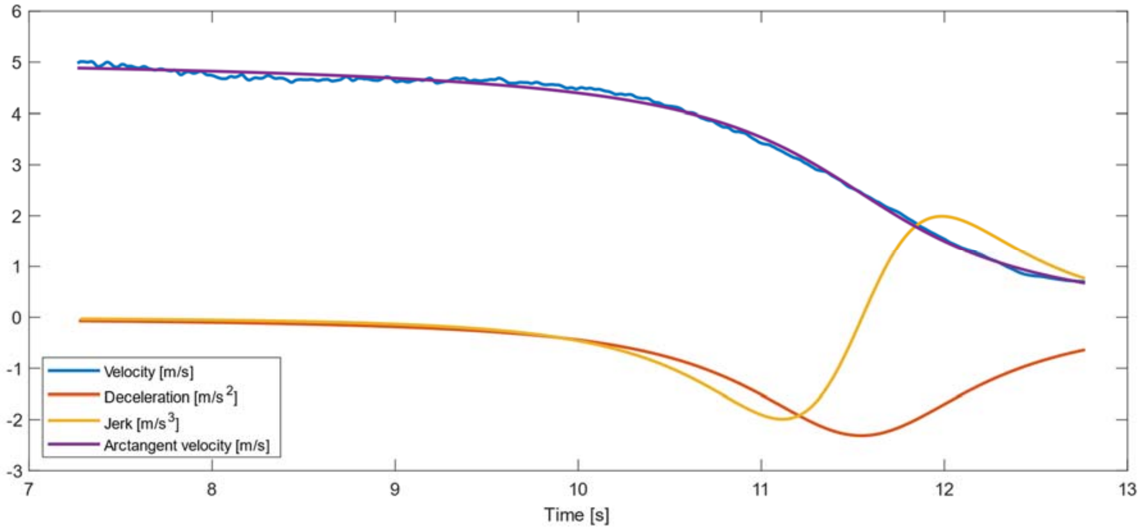

Figure 1. A plot of velocity, deceleration, and jerk in a comfort braking maneuver for one participant riding e-bike.

4 DISCUSSION

This study exemplifies a method that can rapidly compute the minimum deceleration and jerk for modelling MMVs braking maneuver. The velocity curve fitted with arctangent function describes the braking more naturally than a uniform deceleration model [7, 9]. There are several potential applications of the models presented here. First, in threat assessment of ADAS for low-speed scenarios, the arctangent speed function may be used as a new braking model to calculate required deceleration and jerk more accurately than to calculate with a constant jerk and linear deceleration model. Second, in Euro NCAP safety tests, the model can be used for planning of speed and trajectory for a robot MMV. The arctangent model is deterministic and may not be as ecologically valid as models obtained from large naturalistic databases by using other modelling approaches that can incorporate the road user variability (e.g., Bayesian [8], and deep learning [11]). However, due to its simplicity and low computational complexity, the arctangent model is suitable for both ADAS implementation and simulating MMVs' behavior in large road networks.

5 ACKNOWLEDGEMENTS

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Constructing Model of Bicycle Behavior on Non-signalized Intersection Using Nonlinear Autoregressive Exogenous Model

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1 INTRODUCTION

This study focuses on bicycle travel flow to prevent traffic accidents at non-signalized intersections. A bicycle's behavior can be characterized by various parameters, such as travel speed, position, trajectory, acceleration, and deceleration. The prevention of vehicle collisions with bicycles traveling at 10–15 km/h was regulated in the Advanced Emergency Braking System (AEBS) for passenger cars in regulation No. 152 of the World Forum for Harmonization of Vehicle Regulations in the United Nations. Therefore, it is essential to analyze the characteristics of bicycles in a real traffic environment to prevent traffic accidents involving cyclists. Meijer et al. (2017) investigated bicycle behavior and characteristics using measurement devices installed on bicycles [1]. Ma et al. (2016) conducted a model of acceleration behavior on eleven cyclists using GPS data [2]. And it was pointed out that there was a need for modeling research for more cyclists. Hirose et al. (2021) examined bicycles' both travel speed and trajectory as bicycle travel flows based on data obtained from fixed-point observations at a non-signalized intersection in Tokyo, Japan [3]. This used fixed-point observations to obtain raw data of bicycle travel flows in a real traffic environment and reported various travel speed, trajectory, and acceleration/deceleration patterns for bicycles entering intersections. The purpose of this study was to construct a model of bicycle travel flows based on fixed-point observations. It could simulate actual bicycle behaviors based on data that was obtained from measuring bicycle travel flows for 2828 cases from fixed-point observations. Furthermore, the data was divided into five patterns of bicycles entering intersections, and the accuracy of the model was evaluated for each pattern.

2 METHOD

2.1 Data for bicycle model

In this study, the proposed model was constructed based on data that was obtained from measuring bicycle travel flows for 2828 cases at a non-signalized intersection in Tokyo, Japan. Bicycle accidents were reported at this intersection due to restricted visibility by buildings at the corners of this intersection. The intersection had a stop line before entering the intersection, and the range of modeling was 10 m to the stop line in this intersection. The bicycles' traveling positions, speeds, and acceleration/deceleration were analyzed based on these data. Our previous study reported that most bicycles entered the intersection traveling at speeds between 3.13 m/s and 3.76 m/s [4]. In addition, the acceleration/deceleration of bicycles was 0.08–0.34 m/s^2 [4].

2.2 Classification of bicycle behavior

In this study, we focused on multiple patterns of both the speeds and acceleration/deceleration of bicycles traveling through the intersection. Note that the model accuracy would be decrease if all the data were targeted for the model. Therefore, to tackle this issue, we constructed multiple models. In the construction of driver models using nonlinear autoregressive exogenous (NARX), it has been confirmed that the accuracy of the model decreases when the driving speed at the time of model construction differs from the driving speed targeted for modeling [5]. In addition, the data used in this study was classified into the following five bicycle behavior types. Type 1: entering the intersection at a constant speed immediately after deceleration. Type 2: entering the intersection after significant deceleration. Type 3: entering the intersection at a constant speed. Type 4: entering the intersection at a constant speed immediately after acceleration. Type 5: entering the intersection at a constant speed and after repeated acceleration/deceleration. The models were construct for each behavior type.

2.3 NARX model

In this study, we constructed bicycle behavior models using NARX. NARX uses machine learning to build a model of time-series data [5]. The inputs were the distance to the intersection's stop line and the bicycle speed for the NARX, and the output was the acceleration/deceleration of the bicycle. From the analysis described in Section 2.1, bicycles had various accelerations/decelerations before passing through the intersection. Herein, we intended to construct models for acceleration/deceleration based on the natural behavior of bicycles. The internal parameters of NARX were as follows: the number of delays in input and output was 2; number of neurons in the middle layer was 2; and number of epochs was 300. The model's accuracy was evaluated based on the output of the trained NARX model. Evaluation was performed using the evaluation data, which were not used as training data. Because training data affect the model's accuracy, it is possible to build a high-precision model efficiently even if it is constructed from a small amount of data. Therefore, this study used 2000 data as the maximum training data. For comparison of the model's accuracy, three different models were constructed using 500, 100, and 50 data, respectively. The model's accuracy was evaluated from the root mean squared error (RMSE) of the acceleration/deceleration. The RMSE was calculated from the measured data at the intersection and output of the NARX model. The smaller the RMSE value, the more accurate the model. Furthermore, MATLAB was used to construct the NARX model.

3 RESULTS

Figure 1 shows the relationship between acceleration/deceleration, calculated by the model, and distance to the stop line in the intersection. In Figure 1, the bicycle behavior types shown are types 1 and 3. Herein, the zero on the x-axis indicates the stop line of the intersection, and the acceleration/deceleration occurs 10 m before the stop line at the intersection. The blue line denotes the measured acceleration/deceleration of the cyclist at the intersection, whereas the red line denotes the output of the NARX model. Figures 1 (a) and (b) report an RMSE of 12.5×10^{-3}, 2.84×10^{-3}, respectively. Thus, it can be inferred the NARX model was able to simulate bicycle behavior in terms of acceleration and deceleration. Moreover, similar results were obtained for Figure 1 (a) where the RMSE was 12.5×10^{-3}, which had a lower accuracy than that of Figure 1 (b).

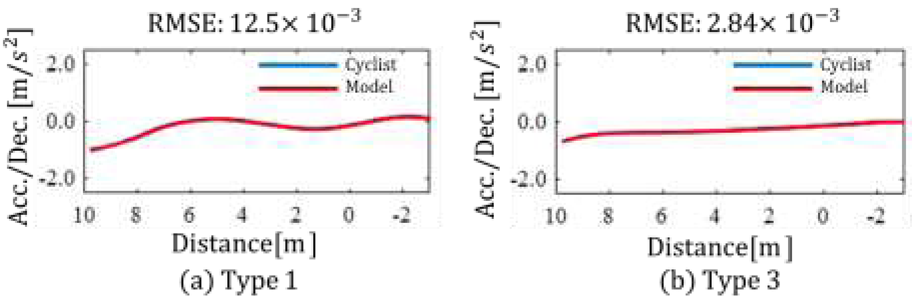

Figure 1: Result of NARX model for acceleration and deceleration of bicycle.

Further, we examined the mean and standard deviation of the RMSE values, listed in Table 1, to evaluate the model accuracy for all data. Table 1 shows the values of both average and standard deviation of the RMSE values of the five bicycle behavior types; the numbers of training data were 2000, 500, 100, and 50. The results showed that the lowest accuracy was obtained with 50 training datasets, and similar accuracy was obtained with the 2000, 500, and 100 training datasets. These results indicate that the model accuracy for bicycle behaviors at non-signalized intersections had less significant effects even if the NARX model was constructed using 100 training data. Reducing the number of training data to below 100 affected the model's accuracy. Regarding the characteristics of the bicycle behavior types, Type 3 had the highest accuracy; Types 2, 4, and 5 had similar accuracy; and type 1 had lowest accuracy among all the types.

Table 1: Result of model accuracy on bicycle behavior types and the number of training data.

	Number of training data							
	2000		500		100		50	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
Type 1	22.361	7.272	21.138	7.741	19.86	5.899	95.719	61.986
Type 2	17.419	7.087	15.95	5.583	17.282	6.362	92.382	57.976
Type 3	10.193	3.751	9.307	2.938	9.926	3.142	71.67	46.985
Type 4	18.935	7.875	16.032	4.764	17.824	5.933	74.717	53.342
Type 5	17.8	7.449	15.937	6.208	17.604	6.479	89.497	58.877

Here, "Types" refers to the classification of bicycle behavior; the values in the table are RMSE × 10^{-3})

4 CONCLUSIONS

This study focused on constructing a model of bicycle traffic flow that can simulate natural bicycle behavior. The data for constructing the model was obtained by measuring the bicycle travel flow for 2828 cases at a non-signalized intersection in Tokyo, Japan. Models were constructed using NARX; the inputs were the distance to the stop line of the intersection and the bicycle speed, and the output was the acceleration/deceleration of the bicycle. Consequently, it was observed that the NARX model could simulate bicycle behavior in terms of both acceleration and deceleration. Furthermore, reducing the number of training data to below 100 affected the model's accuracy. The Type 3 bicycle behavior had the highest accuracy; Types 2, 4, and 5 had similar accuracy; and type 1 had the lowest accuracy among all the types. However, the number and types of bicycle behavior and intersections are limited. This study divides the bicycle behavior types into five, but it is necessary to investigate the model accuracy when further dividing the types. We should apply this model to other non-signalized intersections in further study.

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Automated detection of e-scooter helmet use with deep learning

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Keywords: e-scooter safety, injury prevention, helmets, deep learning, computer vision

1 INTRODUCTION

E-scooter riders have an increased crash risk compared to cyclists [1]. Hospital data finds increasing numbers of injured e-scooter riders, with head injuries as one of the most common injury types [2]. To decrease this high prevalence of head injuries, the use of e-scooter helmets could present a potential countermeasure [3]. Despite this, studies show a generally low rate of helmet use rates in countries without mandatory helmet use laws [4][5][6]. In countries with mandatory helmet use laws for e-scooter riders, helmet use rates are higher, but generally remain lower than bicycle use rates [7]. As the helmet use rate is a central factor for the safety of e-scooter riders in case of a crash and a key performance indicator in the European Commission's Road Safety Policy Framework 2021-2030 [8], efficient e-scooter helmet use data collection methods are needed. However, currently, human observers are used to register e-scooter helmet use either in direct roadside observations or in indirect video-based observation, which is time-consuming and costly. In this study, a deep learning-based method for the automated detection of e-scooter helmet use in video data was developed and tested, with the aim to provide an efficient data collection tool for road safety researchers and practitioners.

2 METHODS

Video data was collected from cycling lanes at two observation sites in Copenhagen, Denmark. In Denmark, it is mandatory for e-scooter riders to use the cycling infrastructure and wear a helmet. To only capture one instance of individual e-scooter riders passing the observation camera, the frame per second (fps) rate in the video data was reduced from 30 fps to 5 fps. As there is no trained object detection algorithm for detecting e-scooters including their riders (*active e-scooters*), an existing object detection algorithm [9] for the detection of persons was used as a first step. This process also detected persons on e-scooters (i.e. e-scooter riders). Once the algorithm identified all the frames with persons, frames with active e-scooters were manually selected for further processing. Then, a rectangular bounding box was drawn around e-scooters and their riders. For each bounding box, helmet use was registered (yes/no). Blurry or partly covered active e-scooters were not annotated. Using this approach, we identified a total of 558 samples of e-scooters (Table 1; *n*=244 with helmet; *n*=314 without helmet). This distribution does not represent the actual helmet use distribution in the observed cycle lanes, as not all collected video data was processed, and an effort was made to balance the number of helmet users and non-users in the dataset. To increase the robustness of our model, we added 114 creative commons images of e-scooters as a *robustness dataset* (consisting of 52 e-scooter riders with helmets, and 62 without). We then split the data up into a training (55%), validation (14%), and test set (26%) (Table 2). As implied by the name, we use the training set to train the detection model, and the validation set to validate the model and prevent overfitting. After training, we assess the model's performance by evaluating it against a test set, which consists of frames that have not been part of the training and validation sets. We end with 374 objects in the training set, 99 objects in the validation set and 174 objects in the test set, some images can contain multiple objects. The overall helmet use percentage of the 174 riders in the test set was 65.5% (114 with helmet and 60 without helmet). We train the YOLO-R object detection model for 500 epochs and save the weights from the best performing model on the validation set. The model is trained with default hyperparameters [9].

Table 1: Class distribution of e-scooters in the dataset.

Class	Total Objects	Site 1	Site 2	Robustness Set
E-scooters without helmet	377	123	191	62
E-scooters with helmet	296	140	104	52
Total	673	263	295	114

To evaluate the detection accuracy, we compute descriptive statistics - true positive (TP), true negative (TN), false positive (FP), false negative (FN) - to calculate the Precision and Recall and the mean Average Precision (mAP) of the detection. Precision is calculated by TP / (TP + FP) and describes how accurate the model is, when it predicts an object to belong to a specific class. Recall is calculated by TP / (TP + FN) and describes how many of the actual objects the model detects within a specific class. The two metrics Precision and Recall create a trade-off between correctly classifying each object and capturing all objects, i.e. if precision is maximized, the model will only detect an objects if it is very confident, thus resulting in few but correct detections, whereas if recall is maximized, the model will not miss objects, but also detect many things that are not of interest, thus resulting in detecting all instance alongside many irrelevant objects. The model evaluation should be independent of this trade-off, and thus it is the standard within object detection to use the (mAP) as an evaluation metric. The AP is calculated as the area under the curve of the Precision Recall Curve, i.e. the average precision for all trade-offs. The mAP is the mean of the APs for the different classes. Accuracy measures are first calculated for detecting active e-scooters (i.e. e-scooter plus rider regardless of the rider's helmet use) and then calculated for helmet use detection.

Table 2: Training, validation, and test set split of the dataset.

Class	Total Objects	Training set	Validation set	Test set
E-scooters without helmet	377	257	60	60
E-scooters with helmet	296	143	39	114
Total	673	374	99	174

Table 3: Model performance on the test set, with a confidence threshold of 0.5.

Class	Total Objects	Precision	Recall	AP@.5
Active E-scooter	174	0.946	0.709	0.981
E-scooter with Helmet	114	0.729	0.833	0.882
E-scooter without Helmet	60	0.503	0.900	0.693
Average over the classes	174	0.616	0.867	0.787

3 RESULTS

Of all 174 e-scooters in the test dataset, 122 (TP) were detected as e-scooters (regardless of rider helmet use). 52 instances of e-scooters were not detected (FN) and 7 e-scooter detections did not actually identify an e-scooter (FP). This represents a Precision of 0.946, a Recall of 0.709, and an *mAP* of 0.981 for the detection of active e-scooter riders (Table 3). For all the riders with helmets, 83 instances of helmet use were correctly identified. In 30 instances, a rider was registered as using a helmet although they were not using one (FP), and in 29 instances a rider was registered as not using a helmet although they were using one (FN). For the calculation of precision, recall and *mAP*, these instances of misclassified helmet use as well as instances, in which the whole e-scooter was either missed or falsely detected are taken into account. Precision for helmet use detection was 0.616, and Recall was 0.867, representing an *mAP* of 0.787. Algorithm-registered helmet use for the test set data was 47.7% (see Figure 1 for examples of detections on test set).

Fig 1: Sample frames from detections on the test set (anonymization added for privacy data protection).

4 DISCUSSION

We investigated the feasibility of a deep learning-based object detection algorithm for the detection of e-scooter riders' helmet use in video data. For the general detection of active e-scooter riders, our study revealed an accuracy of *mAP 0.981*. This indicates that deep learning-based e-scooter detection can be useful tool to detect and extract occurrences of e-scooter riders in video data. For e-scooter riders' helmet use, the trained algorithm registered a helmet use rate of 47.7% for the test set data, which is considerably lower than the actual helmet use in the test data (65.5%). Further analysis of the accuracy measures reveals comparatively high inaccuracies in the precision of the detection of e-scooters without helmets. Further research is needed to increase accuracy in helmet use registration.

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A Modelling Study to Examine Threat Assessment Algorithms Performance in Predicting Cyclist Fall Risk in Safety Critical Bicycle-Automatic Vehicle Interactions

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Keywords: cycling safety, car-bicycle conflicts, fall risk, threat assessment algorithms, automated vehicles

1 INTRODUCTION

Falls are responsible for a large proportion of serious injuries and deaths among cyclists [1-4]. A common fall scenario is loss of balance during an emergency braking maneuver to avoid another vehicle [5-7]. Automated Vehicles (AV) have the potential to prevent these critical scenarios between bicycle and cars. However, current Threat Assessment Algorithms (TAA) used by AVs only consider collision avoidance to decide upon safe gaps and decelerations when interacting with cyclists and do not consider bicycle specific balance-related constraints. To date, no studies have addressed this risk of falls in safety critical scenarios. Yet, given the bicycle dynamics, we hypothesized that the existing TAA may be inaccurate in predicting the threat of cyclist falls and misclassify unsafe interactions.

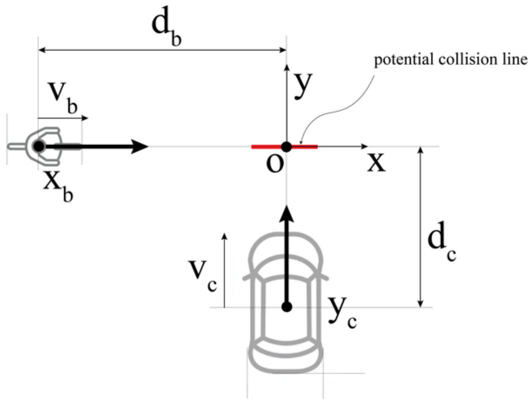
To test this hypothesis, this study developed a simple Newtonian mechanics-based model that calculates the performance of two existing TAAs in four critical scenarios with two road conditions. The four scenarios are: (1) a crossing scenario and a bicycle following lead car scenario in which the car either (2) suddenly braked, (3) halted or (4) accelerated from standstill. These scenarios have been identified by bicycle-car conflict studies as common scenarios where the car driver elicits an emergency braking response of the cyclist [8-11] and are illustrated in Figure 1. The two TAAs are Time-to-Collision (TTC) and Headway (H). These TAAs are commonly used by AVs in the four critical scenarios that will be modelled. The two road conditions are a flat dry road and also a downhill wet road, which serves as a worst-case condition for loss of balance during emergency braking [12].

2 APPROACH

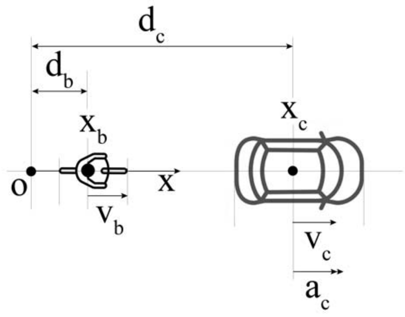
The Newtonian mechanics-based model can calculate for a set of interactions (varying combinations of initial distances d_b, and d_c, and initial speeds v_b and v_c, see Figure 1) whether a fall of the cyclist or collision between the vehicles occurred. For the same range of interactions we determined whether the TTC or H predicted the interaction was safe or unsafe. The predictive performance of the TTC and H was defined as the proportion of misclassifications of unsafe interactions.

3 RESULTS

The proportions of misclassifications of all scenarios, TAAs and road conditions are numerically presented in Table 1 and are visualized in Figure 2 for a crossing scenario on a flat dry road and a TTC threshold of 1.2 seconds. The results show that for a crossing scenario on a flat dry road a TTC threshold of 1.0 and 1.2 seconds misclassified respectively 34% and 9% of the unsafe interactions as safe. This proportion was 22% for a bicycle following a suddenly braking car and a TTC threshold of 2.0 seconds, and 1% for a halting car. For H, the misclassifications were respectively 0% and 4% in these scenarios. For downhill riding on a wet road, the



(a)



(b)

Figure 1: Top view of two types of bicycle-car interaction: (a) A bicycle-car crossing interaction with the location of the bicycle center, x_b, and the car center, y_c, in reference to the origin O of the global fixed coordinate system. The thick red horizontal line at the origin is the potential collision line. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. (b) A bicycle following lead car scenarios with the location of the bicycle center, x_b, and the car center, x_c, in reference to the origin O of the global fixed coordinate system. The initial distances from the origin are d_b for the bicycle and d_c for the car. The initial velocities are v_b for the bicycle and v_c for the car. The constant acceleration of the car is a_c, which is negative for the suddenly braking car scenario, zero for the halted car scenario and positive for the accelerating car scenario.

Table 1: Proportions of misclassifications in % between the Newtonian mechanics model and TTC or H for the four critical scenarios and for a flat dry road and a downhill wet road.

	flat dry road		downhill wet road	
Model interaction outcome prediction	safe	**unsafe**	safe	**unsafe**
TTC interaction outcome prediction	unsafe	**safe**	unsafe	**safe**
crossing scenario				
TTC threshold: 1.0 s	0%	**34%**	0%	**35%**
TTC threshold: 1.2 s	0%	**9%**	0%	**11%**
bicycle following suddenly braking car scenario				
TTC threshold: 2.0 s	8%	**22%**	0%	**51%**
H threshold: 1.8 s	19%	**0%**	0%	**17%**
bicycle following halted car scenario				
TTC threshold: 2.0 s	3%	**1%**	0%	**16%**
H threshold: 1.8 s	1%	**4%**	0%	**20%**
bicycle following car accelerating from standstill				
TTC threshold: 2.0 s	21%	**0%**	14%	**0%**
H threshold: 1.8 s	17%	**0%**	10%	**0%**

proportion of misclassifications increased by at least 15%. In contrast, for the accelerating car scenarios, the classifications were too conservative by misclassifying 17 to 21% of safe interactions as unsafe.

4 CONCLUSIONS

The findings of this study illustrate that existing TAAs for AVs, which do not take bicycle specific balance-related constraints into account, cannot accurately predict the threat of a cyclist fall and take decisions that either put cyclists at a high risk of injury or are detrimental for traffic flow. The results of the simple model support our hypotheses, stress the urgency for further study, and justify the investments required to collect data about critical bicycle-car interactions.

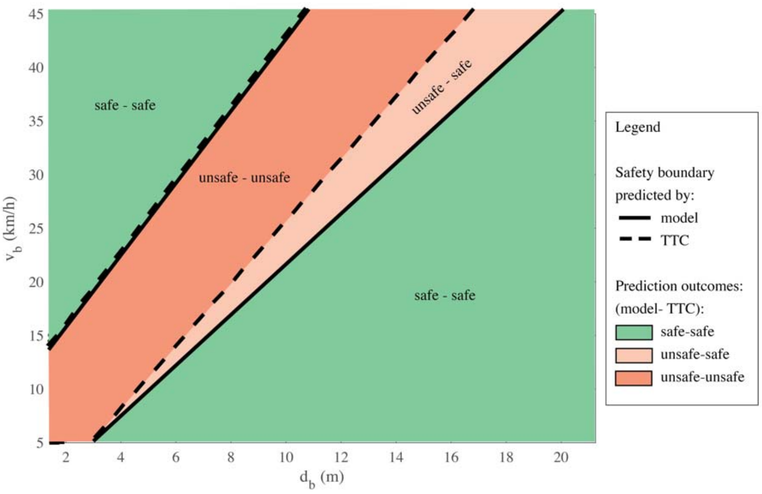


Figure 2. Comparison of misclassifications between the Newtonian mechanics-based model and a TTC with a safety threshold of 1.2 s for the bicycle-car crossing scenario and a dry flat level road. The set of interactions considered are all combinations for an initial position of the bicycle (d_b) between 2 to 21 m and an initial velocity of the bicycle (v_b) between 5 to 45 km/h. All other parameters were kept constant. The green safe-safe area and dark red unsafe-unsafe area are combinations where the prediction of the TTC agrees with the outcome of the model, whereas the light red unsafe-safe area are combinations where the TTC predicts a safe but the model outcome is an unsafe interaction. The percentage as a fraction of the square area are: safe-safe 66%, unsafe-unsafe 25%, unsafe-safe 9% (see Table 1).

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The Role of Bicycles in Driver Assistance Regulations and NCAP – Status and Outlook

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Keywords: driver assistance systems, active safety, regulations, UN ECE, Euro NCAP

1 INTRODUCTION

Over the last years, bicycles have been addressed in newly developed driver assistance systems for passenger cars on a voluntary basis, and beginning with the blind spot assist systems, this tendency has been picked up by vehicle regulations and systems are made mandatory.

This paper intends to give a detailed summary of which vehicle regulations are currently addressing bicycles, when they come into force and if they will be mandatory in the EU. Also, the performance of already available active safety systems for bicycles (not covered by regulatory requirements) and their technological potential will be included.

2 VEHICLE REGULATIONS COVERED IN THE PAPER

The first vehicle regulation developed at UN ECE regarding bicycles was the blind spot information system for heavy vehicles, UN R151, which will be mandatory from July 2022 for newly type-approved vehicles (new registrations form July 2024) in Europe. It requires the vehicle to give a signal for those cyclists that would be endangered if the vehicle would start a right turn. The latest supplement amended the regulation with a new test procedure that not only checks if the information signal is given in time to avoid the accident, it also would allow testing of automated braking in right-turn situations.

Automated braking systems for passenger cars and light commercial vehicles are required to brake for bicycles, those systems will be mandatory in the EU for newly type-approved vehicles from July 2024 (new registrations from 2026). Accidents have to be avoided with crossing bicycles (15 km/h) up to driving speeds of up to 40 km/h.

For all those regulations, the theoretical background that lead to the performance requirements will be explained in detail. Also, new regulations do not specify single worst-case test cases anymore, but they specify a broad range of situations where the systems need to fulfil the performance requirements. This new style of regulation-writing will be explained as well.

The German national automated driving regulation requires automated vehicles (typically fleet-operated shuttles) also to address bicycles; collisions with crossing bicycles have to be avoided up to a travelling speed of 25 km/h.

3 EURO NCAP BICYCLE TESTS

Euro NCAP measurements for bicycle assistance functions are included in Euro NCAP's star rating for new passenger cars since 2018. The performance of rated cars from the beginning up to the latest vehicles will be (anonymously!) analysed, showing a massive increase in performance since 2018. Also, NCAP adjusts the scenarios for accidents between bicycles and passenger cars over the years, an overview of the development of those scenarios will be included in the paper.

4 OUTLOOK

Based on what is presented, the authors will perform an outlook towards what can be achieved by active safety systems (=automated braking for bicycles) and what typical and relevant accident situations are not yet covered (for instance: heavy vehicles with crossing / stationary bicycles in front of the vehicle).

5 CONCLUSIONS

Bicycles are addressed by a variety of active safety systems in vehicle regulations (all of which had been introduced into European legislation by the "General Safety Regulation" 2144/2019) and also in Euro NCAP. This paper aims at showing the community what is available, why the performance requirements are selected the way they are, and what is missing.

6 INVOLVEMENT OF THE AUTHORS INTO THE TOPIC

The authors themselves did participate in detail in the development and writing of all relevant regulations (Patrick Seiniger, Jost Gail: R151, R152, revision of R131) and Euro NCAP (Patrick Seiniger, Adrian Hellmann), so they are able to provide first-hand knowledge. Presenter and lead author will be Patrick Seiniger.

Understanding the interaction between cyclists and automated vehicles: Results from a cycling simulator study

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Keywords: cyclists' interaction, vulnerable road users, computational models, automated vehicles.

1 INTRODUCTION

Cycling as an active mode of transport is increasing across all Europe [1]. Multiple benefits are coming from cycling both for the single user and the society as a whole. With increasing cycling, we expect more conflicts to happen between cyclists and vehicles, as it is also shown by the increasing cyclists' share of fatalities, contrary to the passenger cars' share [2]. Understanding cyclists' behavioral patterns can help automated vehicles (AVs) to predict cyclist's behavior, and then behave safely and comfortably when they encounter them. As a result, developing reliable predictive models of cyclist behavior will help AVs to interact safely with cyclists.

Cyclists' conflicts with vehicles most often happen in crossing situations when the two road users share the path [3]. Frequent conflicts happen at unsignalized intersections where priority rules determine which road user should pass the intersection first. Even though the priority of passing at unsignalized intersections is with the cyclists, in 42% cases, drivers do not yield for the cyclists in Sweden [4]. Very few studies tried to analyze quantitatively the interaction process of cyclists with vehicles at crossing scenarios. Silvano et al. developed a logit model to predict which agent would yield at the intersection when a conflict occurs [5]. In another study, Boda et al. proposed a computational model to predict driver behavior when interacting with a cyclist at unsignalized intersection. This model mainly predicts when drivers initiate braking and for how long they brake [6]. However, what is lacking in previous studies is that they either focused on the driver's side or they did not include detailed information from the cyclists.

Cycling simulators provide a safe and controlled environment to conduct tests with participants under different configurations. They are powerful tools to imitate real environments with the chance to repeat the scenarios. Further, a cycling simulator may be employed to measure participant's interaction with vehicles at intersections in a safe way, because collisions cannot result in damages or injuries. This study investigated cyclists' response process when they interact with a crossing vehicle at an unsignalized intersection. We propose quantitative models to predict cyclist behavior at intersections and a qualitative explanation of the interaction.

2 METHODOLOGY

The cycling simulator at VTI (the Swedish national road and transport research institute) facilities was used to imitate a real intersection in Gothenburg, Sweden. The simulated intersection is an unsignalized intersection with three legs, and conflicts between straight moving cyclists and vehicles that are coming from the right side were investigated (GPS coordinates: 57°42'31.1"N, 11°56'22.9"E). In Figure 1, the layout of the intersection and the moving direction of interacting agents are depicted. After some pilot tests, the independent variables for the experiment narrowed to three different times to arrival at the intersection (TTA) and two visibility distances (FOV distance). Three intersections without oncoming vehicle were included in between the trials to break the participant's expectation. At the end of the trials, a surprise event was included: specifically, in this trial the interacting vehicle was a truck instead of a car.

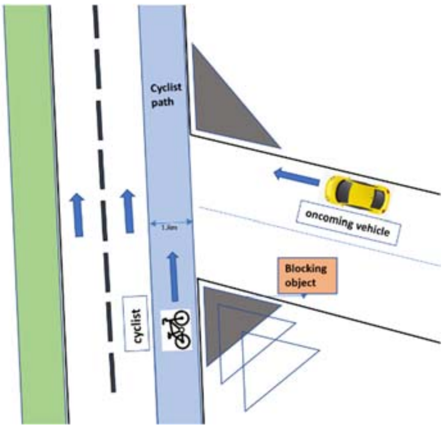

Figure 1: Layout of the intersection considered for the simulator.

Figure 2: Bike simulator and VR setup for the experiment.

The inclusion criteria comprised being 18-45 years old, riding a bike at least once a month, not wearing prescribed eyeglasses, having no physical disabilities, and being under 180 cm of height. Two questionnaires were also filled out during the experiment. The first questionnaire was about demographic information and participant's experience in the simulator. The second questionnaire is called the misery scale, and it was used for capturing the level of discomfort or dizziness that participants experienced during the experiment. It should be noted that a virtual reality headset was used in this experiment to visualize environment. In Figure 2, the experiment setup and the bike simulator can be seen. Sensor data were collected during the experiment and included kinematic information of the car and the cyclists, pedaling, steering angle, and head movement.

3 RESULTS

So far, 14 participants have been tested in the simulator; they had an average age of 29 years (SD = 8.4; range = 19-42). The participants included four women with an average age of 28.8 years and ten men with an average age of 29.1 years. Five participants completed all the trials, and the rest of the participants did not because they showed some signs of motion sickness, and the experiment stopped at that point. The data loss varied much across participants; in fact, the participants that completed only some trials passed the intersection from zero to 11 times (the total number of trials was 12).

Preliminary results show that each participant behaved similarly when the independent variables time to arrival to the intersection and field of view distance changed. Six out of 14 participants that succeeded in doing most of the trials were chosen for the analysis. In Figure 3, cyclists' speed profiles are depicted when the TTA changed, and the rest of the variables were kept constant. As is shown in the figure below, changing TTA values had no major effect on participants' behavior. No significant difference was found either when the FOV changed. Based on interviews, the participants expressed that lacking a driver inside the car to communicate was a major reason to behave safely in most trials (which resulted in cyclist yielding). This experiment is ongoing, and the results will be completed before the conference.

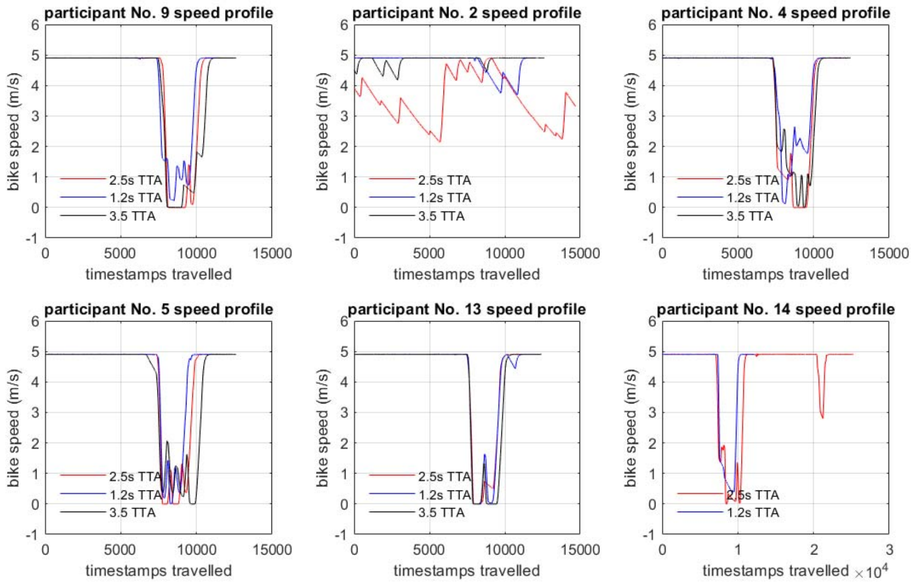

Figure 3: Cyclists' speed profile for different time to arrival (TTA) to the intersection values

4 DISCUSSION

According to the results and interviews, in most cases, participants chose to be safer by yielding to the vehicle because they could not communicate with the driver. Therefore, cyclists' behavior in this experiment implies the importance of implicit communication for interaction between cyclists and vehicles. This experiment is ongoing and will soon test more participants to increase the sample size. Full results will be presented at the conference and included in our paper. Our models will include 1) the cyclist's actions during the interaction (e.g., pedaling, braking, and head movement) and 2) subjective measurement results about the motion sickness and participant's experience during the test.

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Cyclists' experiences in urban longitudinal traffic scenarios and their requirements for designing interactions with highly automated vehicles

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Keywords: cyclist, highly automated vehicle, cyclist-vehicle interaction, external human-machine-interfaces

1 MOTIVATION & STUDY OBJECTIVE

As cycling becomes more popular and automated driving is on the rise, it can be assumed that in the city of the future highly automated vehicles (HAVs) and cyclists will share the same roads. Yet only little is known about how cyclists announce their maneuvers to motorized vehicles or how they communicate and interact with them. Knowledge on these aspects is currently missing to guide the design of cyclist-HAV interactions. Situations where a cyclist rides upfront a vehicle, will be especially challenging for HAVs, such as when a cyclist (A) avoids an obstacle on the road section ahead, (B) merges onto the road from an ending cycling path, or (C) leaves the road turning into a driveway (see Figure 1) [1]. Based on the cyclist's intention, the HAV will have to pass or keep following with only limited options to communicate to the cyclist ahead. Design solutions derived from the well-studied field of pedestrian-HAV interactions cannot simply be transferred to the here considered cyclist-HAV interactions, since in past research successful design concepts for pedestrians were not beneficial for cyclists [2]. Hence, it is vital to investigate the behavior and experiences of cyclists in more detail and to explore possible design solutions for HAV interaction behavior in these situations.

With this study we aim to get more insights into the subjective experience of cyclists travelling in longitudinal traffic, especially during cyclist-vehicle interactions, as well as to derive cyclists' requirements to design safe and desirable cyclist-HAV interactions.

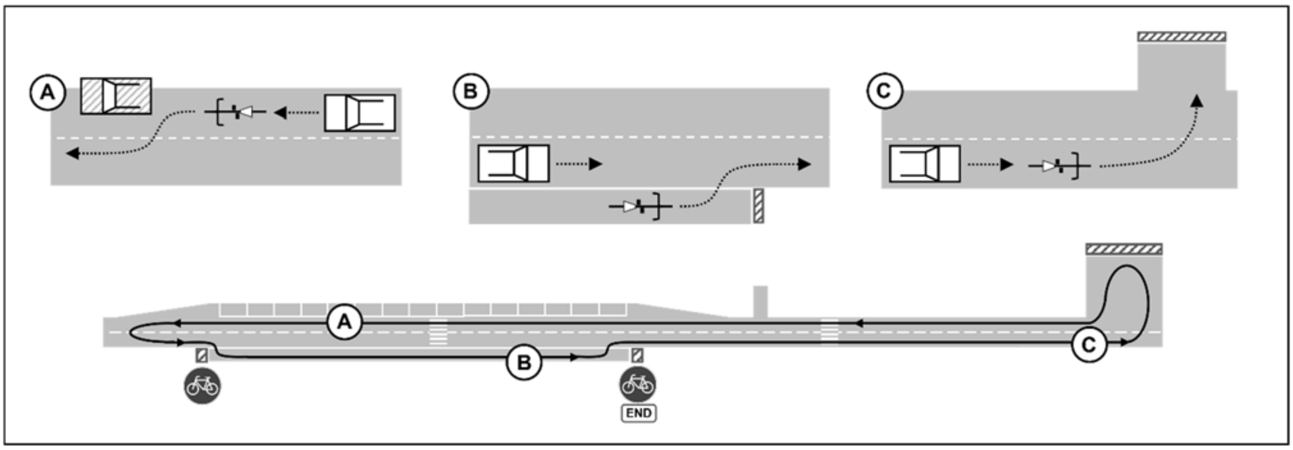

Figure 1: Bird's eye view of the investigated situations (A), (B), and (C) and of the circuit that the participants rode along in the test-track study.

2 METHODS

We conducted a semi-controlled test-track study to safely observe the cyclists' behavior in a controlled environment and to enable them to report their subjective experiences during and after experiencing the situations. To ensure that we could still observe natural cyclist behavior the participants were deceived about the real study purpose. Instead, we told them that we were aiming to explore different cycling patterns with a pedelec with the objective to potentially improve its drive unit. The study design was reviewed and approved by the Ethics Committee of the Technical University of Munich (ethical approval code 426/20 S-SR).

36 company employees (18 female) aged 19-62 (M = 38.4, SD = 12.8) took part in our test track study. Prior to the study, the participants filled in a questionnaire regarding their demographics, their personality, and their daily mobility behavior with a focus on driving and cycling.

Upon arrival, the participants were provided a pedelec that was equipped with data loggers, cameras and a microphone mounted to the handlebar to record their observable behavior as well as their verbal statements. The participants were instructed to ride along the approximately 450 m long circuit depicted in Figure 1 at a speed of 20 km/h. Along the circuit they experienced the three longitudinal traffic scenarios mentioned in section 1.

The test ride consisted of two blocks. The 1st block focused on the observable cyclist behavior during the maneuvers and in spontaneous interactions with a confederate vehicle (BMW 520d Touring, equipped with data loggers and cameras) approaching from behind once per situation as the cyclist rode along the circuit ten times.

Before the 2nd block started, the participants were informed that the confederate vehicle was part of the study. They were instructed to ride along the circuit two more times. They were informed that in both rounds they would again encounter the vehicle in one of the three situations. The specific situation was declared to the participants before. Each situation was covered by 12 participants. During one of the encounters with the vehicle, they were told to let the vehicle pass first and during the other encounter they should pass before the vehicle. This ensured that the cyclists experienced both the situation when they maneuver in front of a vehicle and when the vehicle passes first. During both rounds, the cyclists were instructed to give concurrent verbal protocols about their thoughts during the ride.

After the test ride, the participants were fully debriefed and interviewed about the three situations that they had just experienced during the study. The interview was semi-structured and consisted of two very general questions, regarding (1) comments on the experienced interactions with the vehicle from the viewpoint of developing HAVs and (2) requirements regarding the communication and interaction behavior of HAVs in the experienced situations. The interviewer would ask more detailed questions about the topics that the participants mentioned during the interview.

To explore the subjective cyclist experience in the examined situations, the presented results will be based on the verbal protocols and cyclist behavior of the 2nd block and on the final interviews.

3 ANALYSIS & RESULTS

All verbal protocols and interviews were transcribed verbatim. Then a qualitative content analysis [3] was performed. Qualitative content analysis provides a systematic approach to analyzing textual data using deductive (theory-based) categories or inductive categories that are revealed from the participants' statements.

For the verbal protocols we categorized all verbal statements by the participants regarding the relevant main concepts in the given situations and compared them to the observed cyclist behavior.

To categorize the interview data, we used a mixed approach of deductive and inductive categories. The subcategories for the main categories 'experience' (interview question no. 1) and 'requirements' (interview question no. 2) were created inductively with the aim of systematically organizing the verbal statements from the participants and to discover their underlying needs regarding the design of HAV interactions. The main categories 'message type', and 'HMI type' were derived deductively from the literature to systematically collect information requests and actual human machine interface (HMI) design solutions formulated by the participants. All statements from the participants regarding the message type were categorized into 'HAV automation status', 'environmental perception', 'planned next HAV behavior', and 'HAV cooperation/request' according to [4], who derived the message types from a literature review on nowadays human-human traffic interactions. All statements regarding potential HMI solutions were categorized according to the HMI types for external communication, as proposed by [5] i.e., 'dynamic HMI' and 'external HMI' and their proposed subtypes. Two independent raters paraphrased and categorized a subsample of the data to determine the category system combining deductive and inductive categories. Using the resulting category system another subsample of interviews was categorized by the two raters. The results were then compared to assess the intercoder agreement.

As one main finding, the cyclists reported that the auditory channel was very important when riding in urban traffic in general and particularly in the experienced situations. Several participants announced the presence of the following vehicle before they performed any observable behavior e.g., a shoulder glance, or stated that they require an approaching vehicle to clearly announce its presence. Consequently, adding a message type 'vehicle presence' to the already recommended message types by [4] is important for cyclists interacting with an HAV approaching from behind. The cyclists reported the vehicle's engine noise to be an important channel to announce that a vehicle was present and to also predict its next maneuver or willingness to cooperate. Designing the driving behavior and the related sound produced by the vehicle seems vital, especially when considering that HAVs may also be electrified and therefore only produce little natural noise. Some cyclists discussed additional external HMIs regarding their usefulness and desirableness as well as more general required characteristics of the HAV. Additionally, important inductive categories derived from the participants' statements were not limited to the design of HAV communication and interaction behavior e.g., 'infrastructure' and 'connectivity'.

4 CONCLUSIONS

The study provides insights into how cyclists subjectively experience riding in longitudinal traffic and interacting with a vehicle approaching from behind. The presented findings offer a more holistic view on the design of HAV interaction behaviour with vulnerable road users, complementing the findings from research on pedestrian-HAV interaction. Because of its explorative approach the study further promotes the formulation of research questions and hypotheses to be focused on in future studies. This all contributes to achieving save and desirable future interactions between cyclists and HAVs, considering the cyclists' needs from the very beginning of the design process.

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Real-World Interactions between Cyclists and Automated Vehicles – A Wizard-of-Oz Experiment

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Keywords: cyclists, automated vehicles, interactions, road safety.

1 INTRODUCTION

The introduction of automated vehicles (AVs) changes the way road users interact and communicate. In AVs, informal communication such as eye contact or gestures with other road users is omitted. Because interaction should still be objectively and subjectively safe, many studies are currently focusing on the communication processes between (automated) vehicles and predominantly vulnerable road users (VRUs), like pedestrians and cyclists [1]. These road users are highly at risk of being fatally injured in road traffic accidents, with the WHO reporting pedestrians and cyclists account for 32 % of all fatalities in Europe [2].

The interaction and communication between pedestrians and AVs have already been analyzed in observational and experimental studies. Cyclists are a less researched topic in this context, even little is known about current interaction processes with manually driven vehicles. However, the bicycle is a means of transport that is and should be promoted, especially in light of the desired change in transport. At the same time, compared to pedestrians, its use involves a potentially higher risk due to the higher speeds and less flexible directional adjustments. To ensure that the introduction of automated vehicles does not lead to less frequent use or - even worse - more accidents, it is necessary to investigate how cyclists interact and communicate with motorized road users and whether this can be transferred to the interaction with automated vehicles.

Do cyclists, for example, notice explicit communication from other road users, like facial expressions or gestures? Are their decisions based on such explicit communication or do they rather use movement signals, i.e. implicit communication, to assess whether they can continue cycling or not? On the other hand, do cyclists themselves communicate more explicitly or implicitly? So far, only a few studies have dealt with these questions, some of the insights are briefly presented next.

In a driving simulator study by Hou et al. [3], participants had to drive around an obstacle in their lane and move into the left lane to do so. They had to decide whether to do this in front of an approaching AV or wait until it had passed them. 16 of the 18 participants stated that they had decided to move into the left lane mainly based on the vehicle's position. Nuñez Velasco *et al.* [4] came to similar conclusions. Here, cyclists decided to cross in front of the vehicle primarily based on the distance between the bicycle and the car as well as the right-of-way rule. The automation status of the vehicle had no influence. This was also shown in a photo experiment by Hagenzieker *et al.* [5]. Here, subjects did not believe they were better recognized by automated vehicles. However, there were tendencies for participants to have more confidence in the human driver of manually driven vehicles than in AVs. But the differences were strongly influenced by the context. Subjects trusted the AV more than a human driver in situations where they had the right of way, while the opposite was true for situations where the vehicle had the right of way. What such studies have in common is that they do not look at realistic behavior, but conduct the experiments in a controlled laboratory with the use of videos or photos.

Field studies addressing this issue are even rarer and are mostly limited to observations. For example, in a field study with automated buses in Sweden the buses slowed down in complex situations, e.g. when they were overtaken by another vehicle. As a result, following cyclists suddenly steered away from the bus and sometimes rode into oncoming traffic [6]. Here, the participation of AVs in road traffic not only led to negative subjective safety assessments but also reduced objective safety. Such a behavioral adaptation was also shown in the CityMobil2 project. After some time, cyclists avoided getting too close to automated shuttle busses. If this could not be prevented, they accepted to travel very close to the AV instead of letting it pass a narrow section of the road first, for example [7]. However, current concepts of automated buses are not fully comparable to automated cars due to their very slow and defensive driving style as well as their unfamiliar outer appearance. Initial surveys of interactions with Uber´s semi-automated cars in Pittsburgh show that cyclists feel safer around them than around human drivers [8].

This shows why it is so important to study the interaction processes between VRUs, such as cyclists, and AVs in real traffic. The algorithms of the AVs must be able to anticipate the behavior of VRUs and thus ensure a subjectively and objectively safe interaction (cyclists should feel and be safe around them). This is the aim of the present study. How do cyclists behave when they encounter an apparent AV for the first time? How do they assess the situation and on what basis do they decide to cross? To answer these questions, a field study will take place in Munich in the summer of 2022, in which such interactions will be observed and the cyclists will be interviewed afterward. The study takes place within the TEMPUS project funded by the BMDV (German Federal Ministry for Digital and Transport).

2 METHOD

In the summer of 2022, we will conduct a field experiment in the city center of Munich, where we analyze interactions between cyclists and seemingly automated vehicles (Wizard-of-Oz experiment), as well as between cyclists and manually driven vehicles (between-subjects design). Structured observations and interviews are included in the analysis to generate both objective behavioral data of the cyclists and subjective experience data of the interaction. The observation site and the interactions we are interested in are shown in figure 1. The right-turning vehicle has a green light at the same time as the crossing cyclists. This site was chosen because of several considerations. First, it ensures that cyclists are confident about their right of way. At the same time, studies have shown that even at signalized crossings, VRUs are hesitant to cross until the vehicle clearly shows that it will stop, so the situation can still require communication [9]. In addition, this site allows us to position the vehicle directly at the red light, so the probability of an interaction with waiting cyclists is high.

2.1 Observation

A tablet-based software tool was developed for the observation. The designed coding scheme includes three different phases of a crossing in front of a turning vehicle at a signalized intersection: before, during, and after the crossing. In each of these phases, certain characteristics of the cyclists' behavior will be annotated. Categorizations are waiting time, distraction, gaze behavior, movement characteristics (e.g., fast, slow, …), and explicit communication. Additionally, the gender and age group, as well as observable handicaps were noted.

2.2 Interview

After an interaction is observed, the cyclists will be interviewed. For this, a station will be set up where cyclists will be invited to answer questions about cyclist safety. Questions will range from sociodemographic information to more specific interaction questions, for example, whether they felt safe in the before-experienced situation. The focus of the questionnaire is the cyclist´s subjective impression of the interaction.

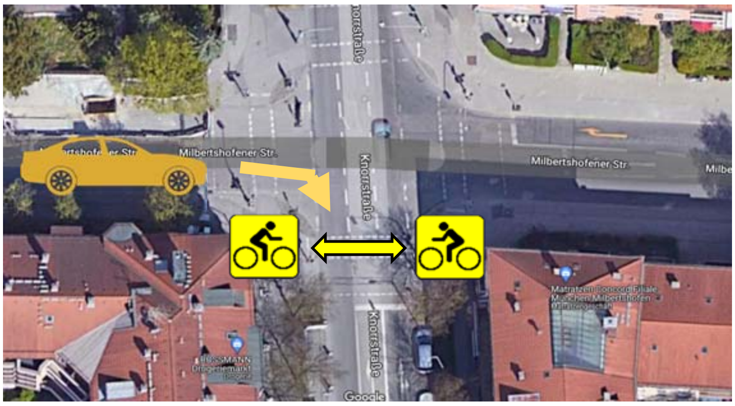

Figure 1: Observation site and interactions we are interested in.

3 IMPLICATIONS

With the help of the results, we hope to be able to assess the effects of AVs on the objective and subjective safety of cyclists. A comparison of interactions between cyclists and seemingly automated vehicles and cyclists and manually-driven vehicles will also allow us to anticipate behavioral changes before AVs enter the market.

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The effects of hourly variation in exposure to cyclists and motorized vehicles on cyclist safety in a Dutch cycling capital

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Keywords: Cyclist safety, Network-wide exposure, Hourly variation in volumes, Cycling infrastructure.

1 INTRODUCTION

While cycling is promoted as a sustainable and healthy mode of transport in many cities in the Global North [1, 2], there are increasing concerns about the safety of cyclists. The increasing bicycle use in urban areas leads to a more intensely used cycling network, resulting in safety risks for cyclists [3]. Since 2010, the number of bicycle fatalities stagnated and the number of severely injured cyclists increased by 28% until 2018 in the European Union [4]. It is therefore necessary to examine how bicycle use and motorized vehicle use in cities affects the number of bicycle crashes.

To investigate this, the effect of the network-wide hourly exposure to cyclists and motorized vehicles on bicycle crash frequency is examined. That is, the total number of cyclists and motorized vehicles in the whole road network for each hour of the week were estimated and used as the network-wide hourly exposure. This approach allowed us to capture safety impacts of temporal variation in the numbers of cyclists and motorized vehicles in the same network more accurately. It is a different approach compared to most bicycle safety studies, which often only use the daily average of bicycle and motorized vehicle volumes. The work presented here is based on our publication in Safety Science [5].

2 CASE STUDY AREA

The city of Utrecht, the Netherlands is chosen as the case study area considering that Utrecht has the highest bicycle usage levels in the Netherlands and is internationally known for being very bicycle friendly with a well-designed cycling network. For example, in 2015, over 40% of the short trips (1-7 km) were made bicycle, while for cars this was 22% [6]. Altogether, this makes Utrecht a good representation of the Dutch "cycling culture", which positively affects the level of safety. However, as Dutch crash statistics show, the number of cyclists involved in fatal and severe crashes increased in the past ten years and the share of cyclists in these crashes is the largest compared to other road users [7]. This makes Utrecht an interesting case to examine the impacts of the exposure to cyclists and motorized vehicles on bicycle safety.

3 NETWORK-WIDE HOURLY APPROACH

To estimate network-wide hourly bicycle volumes, two data sets are used. First, a GPS-based data set from the Dutch Bicycle Counting Week in 2016 (*Fietstelweek*) is used. This data set is used to represent the temporal variation (hours of the day) in bicycle volumes for the Utrecht cycling network. Second, the Municipality of Utrecht provided an extensive data set containing hourly volumes from sixteen permanent count stations for the years 2015 until 2019. A Support Vector Regression (SVR) model is fitted to estimate the hourly volumes on road sections without a count station, with the hourly GPS-based volumes as predictor of the hourly volumes from the count stations.

To derive hourly motorized vehicle volumes, two data sets are used. First, hourly motorized vehicle count data are used, which were collected at intersections and other locations with cameras or induction loops. Second, the transport model from the Municipality of Utrecht is used to estimate hourly volumes of missing sections in the first data set. These were estimated by multiplying the average relative hourly volumes of the sections that were available by the weekly motorized vehicle volumes from the transport model.

As the interest of this study is hourly variation in bicycle crashes, and modelling this variation, the total network exposure for each hour of the week is estimated. To obtain these aggregated volumes, the hourly bicycle volumes and motorized vehicle volumes from each road section are aggregated. Crashes are also aggregated at each hour of the week, based on their occurrence time, resulting in an hourly bicycle crash frequency. To illustrate, Figure 1 shows the hourly variation in bicycle volume, motorized vehicle volume and bicycle crash frequency.

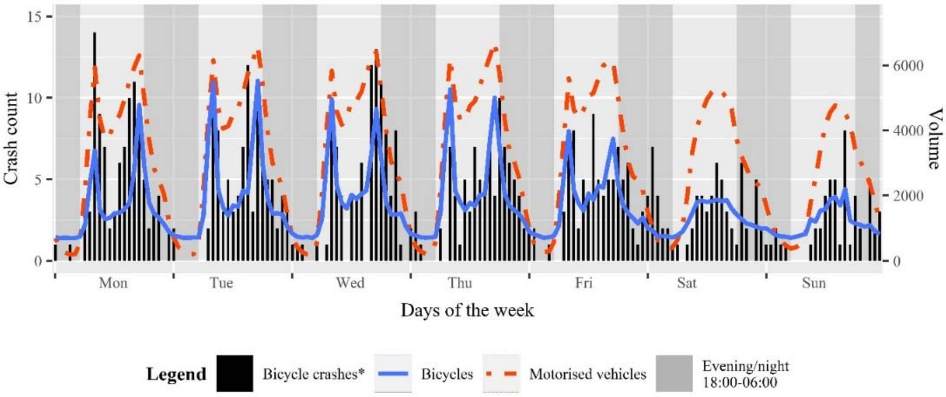

Figure 1:Hourly variation in bicycle volumes, motorized vehicle volumes, and bicycle crashes (*black bars) in the network of Utrecht, the Netherlands.

4 RESULTS

To estimate bicycle crash frequency, seven Negative Binomial (NB) regression models are fitted; one model for every analyzed road category: the full network, 50 km/h roads, 30 km/h roads, 50 km/h roads with separated cycling facilities, 30 km/h road with separated cycling facilities, 50 km/h roads with on-street cycling facilities, and 30 km/h roads with on-street cycling facilities. Both the log of the hourly exposure to cyclists and exposure to motorized vehicles are used as predictors for the models, including a dummy variable morning/day (06:00-18:00) with evening/night (18:00-06:00) as reference category.

The results show that for the full network, for 50 km/h roads, and for 50 km/h roads with separated cycling facilities the exposure to cyclists is a significant positive predictor. This means that during hours with increased exposure to cyclists, the number of bicycle crashes increases as well. Furthermore, the coefficients of the exposure to cyclists are lower compared to the exposure to motorized vehicles. This suggests that during hours where the total network exposure increases, motorized vehicles are a stronger factor for the increase in bicycle crashes than cyclists are. Lastly, the coefficients of the exposure to cyclists show a non-linear relationship with bicycle crashes, meaning that an increase in the exposure to cyclists leads to a less than proportional increase in bicycle crashes.

For the exposure to motorized vehicles, the results show significant positive coefficients for all but one road category, meaning that during hours with increased exposure to motorized vehicles bicycle crash frequency increases as well. Moreover, the size of the coefficients is larger for both 50 km/h roads and 30 km/h roads with on-street cycling facilities compared to other road categories. Thus, bicycle crashes increase more on these roads when exposure to motorized vehicles increases than on the other road categories. Furthermore, the models show that the exposure to motorized vehicles is more linearly related to bicycle crashes compared to the exposure to cyclists. For comparison, Figure 2 illustrates the difference between the coefficients of the exposure to cyclists and motorized vehicles per road category.

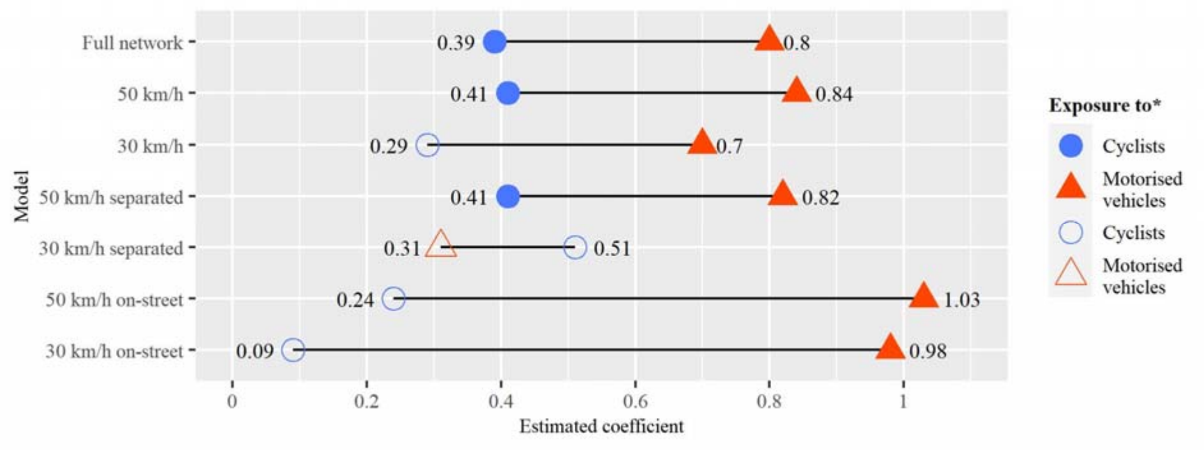

Figure 2: Difference between exposure to cyclists and motorized vehicles. *Hollow shapes are not significant

Finally, morning/day (06:00-18:00) is an important negative predictor for most of the road categories. Negative in this sense means that, after correcting for exposure, fewer bicycle crashes occur during the morning and day compared to the reference category evening/night (18:00-06:00).

5 CONCLUSIONS

The following conclusions can be drawn from the results:

1. Bicycle crash frequency increases less than proportional with an increase in the exposure to cyclists and more linearly with an increase in the exposure to motorized vehicles.
2. Peak hours have the highest levels of the total network exposure, which consequently leads to higher numbers of bicycle crashes.
3. In absolute numbers, cyclists are more involved in crashes during the day than during the evening and night. However, after correcting for exposure, the evening and night are less safe than the daytime hours.
4. Bicycle crashes on 50 km/h roads are more sensitive to an increased exposure to motorized vehicles than bicycle crashes on 30 km/h roads.
5. Separated facilities are found to be safer than on-street cycling facilities given the motorized vehicle volumes.

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Single-bicycle crashes in Finland – characteristics, risk factors, and safety recommendations

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Keywords: cycling safety, bicycling, crash, road safety, single-bicycle crash.

1 INTRODUCTION

Physical inactivity increases the risk of multiple diseases with extensive personal and societal effects [1]. For instance, the annual economic cost of physical inactivity is estimated to be more than 80 billion euros in the European Union (EU) [2]. One measure to increase physical activity is the promotion of active transport modes, such as cycling.

Finland is aiming to increase the mode share of active transport modes to 35–38% by 2030 [3]. In the most recent national travel survey 8% of daily trips were made by bicycle and 22% of daily trips involved walking [4]. A shift from cars to more sustainable transport modes is desirable, however more work is needed to promote cycling safety, with cyclists over-represented in fatal (11%) and serious injuries (32%) when compared to mode share [5].

Amongst cyclist crashes in Finland, single-bicycle crashes (SBCs), where other road users are not collided with, represent more than half of non-fatal injuries [6–7] and 46% of fatal injuries [8–9]. This proportion of non-fatal injuries is similar to findings from other jurisdictions [6]. However, the rate of fatal injuries in SBCs is substantially higher in Finland compared to the average rate in Europe [10], highlighting the importance of understanding SBCs in a Finnish context.

Analyses of SBCs are usually more challenging than crashes between bicycles and motor vehicles because SBCs are typically underreported in police-reported crash data [11]. However, in Finland, road crash investigation teams investigate almost all fatal road crashes, including SBCs. This captures high-quality information on SBCs including their contributory and background risk factors, as well as safety recommendations. Identifying the contributory factors that enable the occurrence of crashes and implementing actions to prevent these crashes can help promote cycling safety [12]. Such analyses and actions are particularly needed in Finland, where there are targets to increase the mode share of cycling.

Given the robust data available through the in-depth investigations undertaken in Finland, this study aims to increase knowledge on SBCs and their safety recommendations by analysing data on fatal cycling crashes in Finland. The study compares the key characteristics, risk factors and safety recommendations regarding SBCs and other cyclist crashes. Although the data for this study is sourced from Finland, the findings are useful in other countries with similar bicycle infrastructure and weather conditions.

2 DATA AND METHOD

This study analyses in-depth investigated crash data on fatal cyclist crashes in Finland from 2010 to 2019. Data was collected from investigations undertaken by the multidisciplinary road crash investigation teams.

In total, 2,442 fatal crashes were investigated between 2010 and 2019, of which 232 involved a fatal injury to a person riding a bicycle. Of the 232 cyclist cases, 82 (35.3%) were SBCs. Of other cyclist crashes (n=150, 64.7%), 137 involved a collision with a motor vehicle, eight cases were collisions with other cyclists and five cases were collisions with pedestrians.

This study presents descriptive analysis of key crash characteristics including cyclists' age, gender, weather conditions, road conditions, location of the crash, and time of the crash. In addition, immediate risk factors (factor that actively influences on the occurrence of the crash), crash mechanisms, background risk factors, and safety recommendations documented by the investigation teams are compared between SBCs and other cyclist crashes. Logistic regression analysis was performed to identify differences between SBCs and other cyclist crashes. Chi-squared tests ($\chi 2$) or Fisher's exact test were performed to identify differences in risk factors and safety recommendations between SBCs and other cyclist crashes. Effect size was assessed using Cramer's V statistic (φc). Statistical analysis was executed using IBM SPSS v.28.

3 RESULTS

3.1 Characteristics of fatal cyclist crashes

Fatal SBCs commonly involved people aged 60–79 (48.8%), males (86.6%), and cyclists not wearing a helmet (76.5%). In addition, these crashes typically occurred in bright or cloudy weather (92.6%), in dry road surface conditions (79.5%) and on a cycle path or a sidewalk (47.6%). In 32.1% of SBCs, a cyclist was under the influence of alcohol. SBCs occurred typically between 8:00 AM and 8:00 PM (61.2%) and during daylight (72.0%). SBCs were most common in summer (45.1%) compared to other seasons and on weekdays (65.9%) compared to weekends.

The results of the logistic regression presenting the differences between SBCs and other cyclists crashes show that males were more often involved in SBCs. In addition, SBCs occurred more commonly on cycle paths or sidewalks, or on the roadway, compared to other cyclist crashes which most commonly occurred at intersections. SBCs were also more common on weekends than on weekdays compared to other cyclist crashes. No other statistically significant differences were identified.

Statistically significant differences were identified when comparing immediate risk factors between SBCs and other cyclist crashes ($\chi 2$ (4) = 159.54, $p < 0.001$, $\varphi c = 0.83$). Cyclist's health issues were the most common immediate risk factors in SBCs (62.2%), but they were not common in other cyclist crashes (1.3%). In other cyclist crashes, the most common immediate risk factor was an observation or anticipation error (74.0%), which only contributed to 7.3% of SBCs.

3.2 Background risk factors in SBCs

Background risk factors are classified as factors that enable the occurrence of the immediate risk factors. The investigation teams identified human factors as the most common contributing factor in both SBCs and other crash types (53.2% in SBCs and 49.0% in other cyclist crashes). The next most common factor was related to the bicycle and equipment (24.3% in SBCs and 24.9% in other cyclist crashes). No statistically significant differences were identified between the main groups of background risk factors ($p = 0.47$, Fisher's exact test).

3.3 Safety recommendations in SBCs

Recommendations regarding the human factors were the most frequent for both crash types (57.5% in SBCs and 43.6% in other cyclist crashes). For SBCs, the next most common recommendations related to regulation (17.3%) and the traffic environment (15.8%). For other cyclist crashes traffic environment was the next most common (30.7%) before regulation (15.5%). The differences between SBCs and other cyclist crashes in the main groups of safety recommendations were statistically significant ($\chi 2$ (3) = 25.36, $p < 0.001$, $\varphi c = 0.16$).

4 DISCUSSION AND CONCLUSIONS

This study presented an analysis of fatal cyclist crashes in Finland between 2010 and 2019 highlighting the characteristics, background risk factors, and recommendations for safety made by the crash investigation teams who investigated each crash. The focus was to explore SBCs and draw comparisons between SBCs and other cyclist crashes. The findings provide insight into the unique characteristics of SBCs.

The study found that SBCs commonly involved people aged 60–79, males, and cyclists not wearing a helmet. Human factors were reported as background risk factors in most SBCs and other cyclist crashes. Risk factors related to illness and use of alcohol in particular were highlighted in SBCs.

Recommendations by the investigation teams related to human factors in SBCs highlight informing cyclists about the risk factors regarding cycling under the influence of alcohol and while fatigued. Sober cycling could also be promoted by introducing a blood alcohol limit for cyclists, which is currently under consideration in Finland. Other recommendations related to human factors included informing cyclists about the use of helmets and better surveillance of underlying medical conditions.

The findings from this study will be further discussed considering the Safe System approach with recommendations regarding the human factors, the bicycle, the traffic environment, and the regulation. Actions regarding all these factors are needed to reduce SBCs and improve cyclist safety.

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Wider view over bicycle accidents: Complementing and extending bicycle accident statistics in urban areas using surveys

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Keywords: Bicycle accident statistics, unreported accidents, accident types, accident hotspots.

1 INTRODUCTION

City traffic planners are striving to adapt their infrastructure to not only increase the number of cyclists but also to ensure that city cycling is both enjoyable and safe. In Switzerland and in many other countries, it is suspected that only one of ten bicycle accidents is reported to the police [1–5]. Only knowing about 10% of the accidents, on top of the fact that there are luckily not many accidents from a statistical perspective, casts doubt about where efforts should be made to improve cycling infrastructure, and how effective the actions taken actually are.

To deal with this lack of data, this paper proposes to use surveys of cyclists besides police records to obtain a more complete picture of the number and location of cycling accidents, including the ones not reported to police, and the locations that cyclists perceive as dangerous. The combination of survey and police reported data gives a considerably different and more complete impression of where there is potential to improve cycling infrastructure, when compared to that obtained using only police reported accidents. This work expounds how the survey responses about hazard perception and unreported accidents help provide a more complete overview of the accident potential of the existing cycling network and how they form a base of immensely useful inputs for planning improvements.

2 STUDY

The two data sets used in this study are police accident data (compiled by police officers when managing accident sites) and survey questions answered by affected cyclists retrospectively.

86% of the personal experienced accidents stated in the survey were not reported to the police. Since the number of accidents is a key factor in the prioritisation of bicycle safety measures, it is important to know where unreported bicycle accidents are happening. The accident severity is another key factor in the prioritisation of bicycle safety measures. 42% of the serious injury accidents, 84% of the slight injury accidents and 88% of the property damage accidents stated in the survey were unreported. Extrapolation shows that the monetised costs of unreported accidents is 4.56 times higher than the police reported accidents. Thus, there is a large amount of accident costs that cannot be spatially allocated. Furthermore, combining not police reported and police reported accidents highlighted key accident locations that appeared to be less important when only police reported accidents were considered.

The type of accident is a key factor when striving to understand how the dangerous situations evolve at an accident site. Unsurprisingly, the police reports showed an overrepresentation of accidents with seriously injured casualties. However, 42% of the accidents with serious casualties stated in the survey were not reported to the police. Furthermore, 84% of the survey accidents involving slight injuries were not reported to the police.

While both data sets contained a high number of single-vehicle accidents, these accidents did not mirror the same leading causes. The combination of police-reported and unreported survey accidents showed a high proportion for the leading cause "acute-angled tram track crossing", whereas the police reported accidents alone showed a low proportion. On the other hand, "Other influence related to inattention or distraction" was the most common leading cause within the police reported accidents, while the combined data set displays this leading cause only in a small part of the accidents. Furthermore, the influence of alcohol showed a much higher representation in the reported accidents than in the combined set.

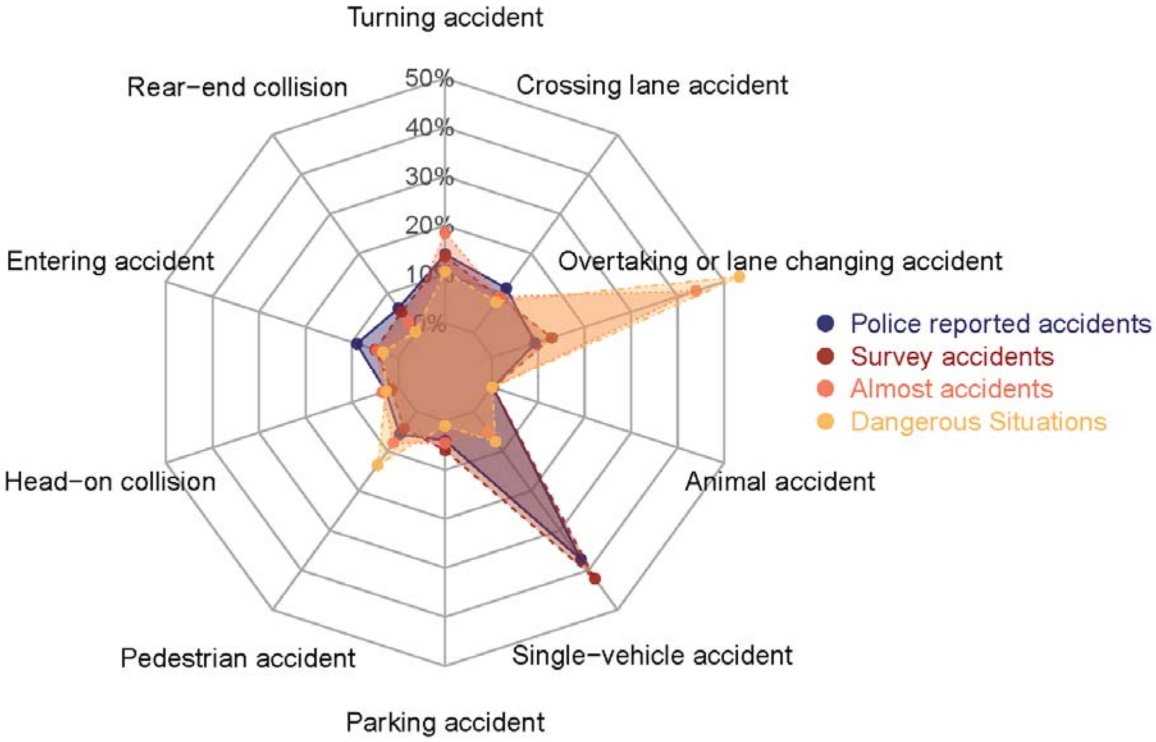

Figure 1: Frequency of accident type groups according to different sources

Another aspect that only a combination of survey and police reported data allows is the comparison of spots that were perceived as dangerous and spots that actually proved to be dangerous. The knowledge about where cyclists perceive danger can be used as indicator of which situations should be reduced for cyclists in order to get more people cycling. Additionally, a comparison between perceived and actual risk can be done. The comparison of the accident type groups of actual accidents, almost accidents and as hazardous perceived situations showed an enormous difference (Figure 1). The actual accidents mirrored in 37% (police reports) or 42% (survey) of the cases single-vehicle accidents. Almost accidents and dangerous situations fell to 44% respectively 53% under the category "Overtaking or lane changing accident". These findings suggest that, regarding these two accident types, there is a big difference between risk perception and actual risk.

3 CONCLUSIONS

Since the prioritisation of infrastructure renewals also builds on results of accident analysis, more efforts should be made to gather knowledge about not police reported accidents. This study shows that a combined view of police and survey accident data leads to a different prioritisation of accidents spots. The presented method represents an approach to gain a more holistic view on accident occurrences. It enables the quantification of the estimated number of unknown cases, reveals their characteristics and thus offers a wider understanding of where prevention measures should be placed. Furthermore, the method has proven to be promising when aiming to collect more information on accident sites and sites or situations that give cyclists the feeling of unease.

In this study, we saw a very clear difference in risk perception and actual risk between accident types. The results beg the question if cities with different styles of cycling infrastructure paint different pictures in that regard. Generally, comparing different cities regarding their number of unknown accidents and the perception of danger by cyclists could establish a basis to measure the success of accident prevention strategies and cycling infrastructure planning.

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Effects of a bicycle detection system on real-world crashes

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Keywords: bicyclist AEB, automatic emergency braking, advanced driver assistance system.

1 INTRODUCTION

More than 900 bicyclists died in motor vehicle crashes in the United States in 2020, which represents a 50% increase from 2010 and the highest number of bicyclist deaths in nearly 35 years [1]. Reversing this trend will require efforts on multiple fronts, including reducing vehicle speeds and improving roadways and vehicles to be more hospitable to cyclists.

Automatic emergency braking (AEB) with cyclist detection is a vehicle countermeasure with potential to prevent bicycle-motor vehicle crashes. AEB systems, which typically warn drivers of an impending collision and brake if drivers do not respond, have been shown to reduce vehicle-to-vehicle rear-end crash rates by 50% [2] and pedestrian crash rates by 27% [3]. Little is known about the real-world effects of AEB with cyclist detection on bicycle crashes.

Subaru's EyeSight system, which includes AEB, has been capable of detecting cyclists in parallel configurations beginning in model year (MY) 2013 in the United States. The ability to detect cyclists in perpendicular configurations was added to some models beginning in MY 2022. The goal of this study is to evaluate the effects of the early version of EyeSight on U.S. bicycle crashes.

2 METHODS

2.1 Data

The presence or absence of EyeSight on MY 2013–2020 Subaru vehicles where the system was an optional feature was identified through vehicle identification numbers (VINs). Bicycle crashes involving these vehicles where the subject vehicle was not backing were extracted from the crash databases of 16 U.S. states during calendar years 2014–2020. State crash databases were coded into a common format, as uniform variables were not available in each state.

Single-vehicle single-bicycle crashes with parallel and perpendicular crash configurations were classified by the vehicle and bicycle directions of travel prior to the crash in the eight states where these variables were available. The bicyclist's action prior to the crash was used as a proxy for configuration in other states, with crashes where the cyclist was riding along the roadway with/against traffic categorized as a surrogate for parallel configurations, and crashes where the cyclist was crossing used as a surrogate for perpendicular configurations. When both variables were available, the configuration was established by the direction of travel and bicyclist action was considered when direction was missing.

Data on the number of days vehicles were insured were obtained from the Highway Loss Data Institute. Crash rates are expressed as crashes per insured vehicle year, with a single vehicle insured for one year or two vehicles insured for six months each equaling one insured vehicle year.

2.2 Analysis

The primary analysis used negative binomial regression to examine the association of EyeSight with bicycle crash rates per insured vehicle year, controlling for calendar year, state, vehicle model year and series, and driver age group and gender.

A secondary analysis used the quasi-induced exposure technique to compare involvement of study vehicles with and without EyeSight in bicycle crashes to crash types that are not sensitive to the system, which were rear-end struck and side struck crashes (i.e., where the study vehicle was the struck vehicle). Quasi-induced exposure is thought to account for where and how much vehicles are driven, and this technique has been used in other evaluations of AEB effects [3,4].

Quasi-induced exposure analysis was conducted with logistic regression using the same covariates as the primary analysis. This analysis was limited to 14 states with variables for vehicle point of impact so that struck vehicles could be identified. The two states without these variables were large (New York and Washington), and so sample sizes were considerably smaller without them. Both methods examined the association of AEB with all bicycle crashes and with single-vehicle single-bicycle crashes with parallel and perpendicular configurations.

3 RESULTS

Study vehicles were involved in 892 bicycle crashes, of which 294 had parallel configurations and 401 had perpendicular configurations. Crash rates were lower for vehicles with EyeSight than without, with the largest difference seen in parallel-configuration crashes (Table 1).

Table 1: Bicycle crash rates per insured vehicle year among Subaru vehicles with and without EyeSight.

System	Parallel configuration		Perpendicular configuration		All bicycle crashes	
	Number	Rate (x100,000)	Number	Rate (x100,000)	Number	Rate (x100,000)
With EyeSight	79	4.3	127	6.8	278	14.9
Without EyeSight	215	5.9	274	7.6	614	16.9
Total	294	5.4	401	7.3	892	16.2

Negative binomial regression revealed that when accounting for covariates, bicycle crash rates in parallel configurations were 29% lower among vehicles with EyeSight than the same models without the system (Rate ratio [RR], 0.71; 95% CI, 0.53–0.96, p = 0.03; Table 2). In contrast, there was little difference in rates of perpendicular (RR, 0.95; 95% CI, 0.74–1.21, p = 0.67) or all (RR, 0.91; 95% CI, 0.77–1.08, p = 0.30) bicycle crashes per insured vehicle year between vehicles with and without EyeSight.

Table 2: Model results of association of EyeSight with bicycle crash risk

Analysis	Parallel configuration	Perpendicular configuration	All bicycle crashes
	RR (95% CI)	RR (95% CI)	RR (95% CI)
Negative binomial regression	0.71 (0.53, 0.96)*	0.95 (0.74, 1.21)	0.91 (0.77, 1.08)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Quasi-induced exposure (rear-end struck non-sensitive crash type)	0.72 (0.49, 1.05)+	0.99 (0.73, 1.35)	0.93 (0.76, 1.15)
Quasi-induced exposure (side struck non-sensitive crash type)	0.72 (0.49, 1.05)+	0.97 (0.71, 1.32)	0.90 (0.72, 1.12)

*p<0.05, +p<0.10; abbreviations: RR, rate ratio; OR, odds ratio

Secondary analyses using quasi-induced exposure included 601 total bicycle crashes, 191 with parallel configurations, and 270 with perpendicular configurations. Effect sizes were similar to the primary analysis

(Table 2), but the association of EyeSight with parallel configurations was no longer statistically significant ($p < 0.10$). The small sample size in the quasi-induced exposure analysis limited power, especially when looking by crash configuration.

DISCUSSION

An early version of EyeSight was effective in preventing bicycle crashes in the parallel configuration it was designed to detect. Yet, a minority of bicycle crashes are in parallel configurations. A study of configurations in single-vehicle crashes involving the fronts of vehicles in the United States during 2008–2012 [5], for example, reported that while about half of bicyclist fatalities involved the cyclist traveling in-line or against traffic, less than 30% of all bicycle crashes were in this configuration. Crossing crashes were more common and accounted for about half of bicycle crashes.

Bicycle detection systems will need to prevent the more common perpendicular configuration to meaningfully reduce bicycle crashes overall. The generation of EyeSight evaluated in this study is older, and current systems exist with increased functionality, including the newest generation of EyeSight available on U.S. vehicles. EuroNCAP includes both parallel and crossing configurations in its AEB cyclist test, which is likely encouraging automakers to include both capabilities in their systems on European vehicles. However, there is currently no consumer information program for bicyclist detection systems in the United States to encourage similar equipment with highly functional bicycle detection systems.

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Analysis and comparison of the driving behaviour of e-scooter riders and cyclists using video and trajectory data in Berlin, Germany

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Keywords: micromobility, e-scooter, vulnerable road users, interaction, safety.

1 INTRODUCTION

As one solution of micromobility, e-scooters have become a trend in Germany. However, the concerns about the safety of e-scooter riders, influence on pedestrians and the parking issues are growing. In 2020, 2,155 e-scooters involved personal injury accidents were recorded in Germany. The number rose to 5,502 in 2021 meaning an increase of 155.31 %. Compared to cyclists (incl. pedelec cyclists), the increasing rate of personal injury accidents in the same period decreased by 8.75 % [1, 2]. Against the background of accidents with e-scooters in cities, prior studies analysed severity and patterns of injuries caused by such accidents [3, 4]. In addition, comparisons are drawn to the consequences of accidents with other vehicles [5, 6]. Some studies also consider the risk of injuries in relation to the miles travelled [7]. The studies provide valuable findings but the approaches focus on the severe consequences of occurred accidents. At the same time, compared to bicycles, the centre of gravity of e-scooters is lower, they are more manoeuvrable and can still reach speeds of up to 20 km/h [8]. The question remains, if these vehicle characteristics are associated with different interaction behaviour.

Hence, the aim of the present study is to reveal the riding behaviour profile in different contexts and investigate e-scooter riders' criticality in interaction behaviour compared with cyclists using surrogate safety measures. We aim to figure out if the interaction behaviour of the two modes differ and what the effects of potential differences are for safety considerations in the system of active mobility.

2 METHOD

As a part of the project Micromobility on pedestrian paths and cycle paths - Conflicts of use and effects on traffic (MMoNK[1]), the general riding behaviour and the behaviour during interactions of e-scooter riders and cyclists were recorded and analysed. The UTRaCar is a converted research vehicle of the DLR equipped with two cameras and a telescopic mast was stationed on three consecutive days (8 a.m. to 4 p.m.) at three different locations in Berlin, Germany in the year 2021 (Figure 1, left). The three measurement locations differed with regard to the district within Berlin as well as the infrastructure (edge, node, square). The video measurements took place on 14th September 2021 in Adalbertstraße, Friedrichshain-Kreuzberg (edge), on 15th September 2021 in Torstr./ Friedrichstr./Chausseestr./Hannoversche Str., Mitte (node) and on 16th September 2021 at Hardenbergplatz, Charlottenburg-Wilmersdorf (square). There are no separate bicycle lanes at any of the three measurement locations. Both cyclists and e-scooter riders have to use the roadway.

[1] The project is funded by the German Federal Ministry of Transport and Digital Infrastructure using resources from the National Cycling Plan 2020 (NRVP). Thanks to the project partners of Difu - German Institute of Urban Affairs.

The videos were recorded in reduced resolution (0.3 megapixels), so that neither faces nor license plates could be recognized. For processing the data, an algorithm for AI-based detection and classification of road users was applied, followed by the association of the detected objects and the determination of movement and position. The position, the size and the category of the road user were detected and calculated. In addition, speed, acceleration and heading of the road user were derived by using the position of the road user.

For the analysis of the interaction behaviour, the Time-To-Collision (TTC), an established surrogate safety measure, was applied. The TTC indicates the time until a collision when two objects continue to move along the same path at their current speed. As a comparative scenario, the pedestrian crossing at the node was selected as an area of interest. Here, the criticality was investigated when e-scooter riders or cyclists and pedestrians meet head-on and the TTC < 5s. Twenty e-scooter riders and 171 cyclists were identified.

3 RESULTS AND DISCUSSION

The number of detected e-scooter riders/cyclists was: at the edge 858/7,700, at the node 1,039/7,927 and on the square 575/1,664.

3.1 Comparison of the riding behaviour of e-scooter riders and cyclists

Infrastructures used were: roadway, pedestrian path and pedestrian crossing, an area on the road marked by markings, mainly at traffic lights. Both e-scooter riders and cyclists use multiple infrastructures in one location, so the total percentage can be over 100%. The most frequently used infrastructure for cyclists at all three measurement sites was the roadway. At all measurement locations, e-scooter riders (edge: 84%, node: 49%, square: 32%) used the roadway less frequently than cyclists (edge: 91%, node: 79%, square: 54%). E-scooter riders were more likely to use the pedestrian crossing (edge: 10%, node: 38%, square: 18%) and the pedestrian path (edge: 7%, node: 12%, square: 50%) than cyclists.

An analysis of the direction of travel on roadways on location edge showed that both e-scooter riders (19%) and cyclists (14%) used the roadway in the wrong direction. The increased number of wrong-way riders can be explained by the fact that e-scooter riders and cyclists were frequently overtaking vehicles in a traffic jam from the left. At the node, there were no wrong-way riders. At the square, people rarely rode in the wrong direction on the one-way street.

At the node, the different velocity profiles (mean, max) of e-scooter riders and cyclists on pedestrian path, pedestrian crossing and roadway were investigated. The average speed for both classes on pedestrian crossing and pedestrian path ranged from approximately 1 m/s to 2.5 m/s, with mean values varying by 1.5 m/s. On the roadway, both e-scooter riders and cyclists travelled slightly faster at about 2.25 m/s.

3.2 Comparison of interaction behaviour of e-scooter riders and cyclists

The interaction behaviour of e-scooter riders or cyclists with pedestrians was investigated on node.

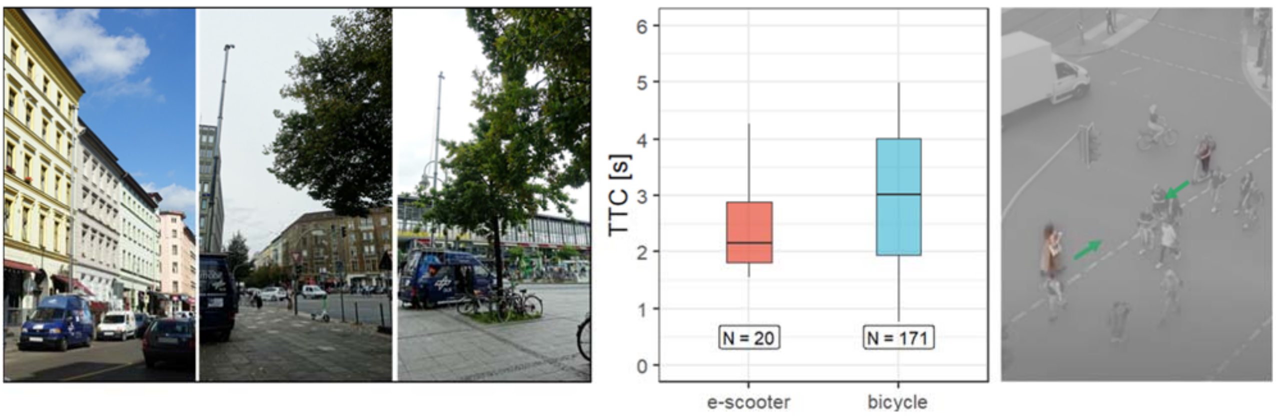

Figure 1: (left) Measurement locations: edge, node and square. (right) Pedestrian crossing at the node: TTC for e-scooter riders and cyclists for the selected area of interest.

The average speed of the e-scooter riders (*M* = 1.7 m/s, *SD* = 0.5 m/s) was higher than the speed of the cyclists (*M* = 1.3 m/s, *SD* = 0.4 m/s) in this scenario. E-scooter riders and cyclists predominantly kept a distance of more than 2 m. On average, the minimal distance between e-scooter riders and pedestrians (*M* = 3.5 m, *SD* = 1.5 m) was slightly higher than between cyclists and pedestrians (*M* = 3.4 m, *SD* = 1.9 m).

The TTC for e-scooter riders and cyclists for the selected head-on scenario is shown in Figure 1 (right). The right side of Figure 1 shows the pedestrian crossing, the area of interest. The minimal TTC for both e-scooter riders and cyclists was generally greater than 2 s, which was above the critical TTC threshold in previous study [9]. For the e-scooter riders, the minimal TTC (*M* = 2.5 s, *SD* = 0.8 s) was lower for cyclists (*M* = 3.0 s, *SD* = 1.2 s) suggesting that pedestrians were at higher risk of encountering e-scooters on pedestrian crossing than encountering bicycles. As described, the results were limited due to the limited case numbers observed at three locations in the period under investigation.

4 CONCLUSIONS

This study provides insight into the riding behaviour of e-scooter riders and cyclists using video recording and exact quantification of interaction behaviour. Results show a slight tendency towards riskier behaviour of e-scooter riders. E-scooter riders used pedestrian path and pedestrian crossing more often than cyclists. In the head-on pedestrians' scenarios, e-scooter riders interacted slightly riskier than cyclists. The velocity of the two vehicle types did not differ significantly. Even though different behaviour is shown, the study does not reveal critical behaviour of e-scooter riders.

Further trajectory analysis of the individual measuring locations and the comparison in different interactions will be carried out in order to find similarities and differences between e-scooter riders and cyclists. Additionally, the demographics of e-scooter riders as well as the impact of parked e-scooters on pedestrians or public traffic will also be part of further analyses.

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Protective behaviours of e-scooter riders in five countries

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Keywords: protective equipment, e-scooters, micromobility, attitudes.

1 INTRODUCTION

Micro-mobility use, such as electric scooters (e-scooters), offers convenience and environmental benefits (Christoforou et al., 2021; Vestri, 2021) and it has increased over the last five years following the introduction of shared e-scooter schemes in the United States in 2017 (Christoforou et al., 2021). Following the introduction of shared e-scooters there has been an observed increase in the number of people choosing to use personal devices (Haworth et al., 2021). E-scooters are typically used more for transport (Sanders et al., 2020), often replacing active travel modes than motor vehicle use (Sanders et al., 2020) although that is location-dependent (Wang et al., 2022). The use of shared and personal e-scooters is primarily associated with travel time and money savings, as well as the enjoyability of the transport mode (Christoforou et al., 2021).

Perceived lack of safety has been shown to influence consumer acceptance (Kopplin et al., 2021). E-scooter riders have been shown to be at risk of trauma to the head and extremities (Bauer et al., 2020), although little is known about the events leading to trauma (e.g., fall as a result of rough terrain, collision with a vehicle). Protective equipment can reduce the risk of incidents (e.g., improving visibility of vulnerable road users) or lessen the risk of injury (e.g., helmets). Generally, little is known regarding the use of helmets and other protective equipment by e-scooter riders, except when injuries occur. Trauma studies have reported low (4.4%; Trivedi et al., 2019) to moderate (46%; Mitchell et al., 2019) use of helmets. While the majority of e-scooter presentations occur during evenings (Vernon et al., 2020), little is known about the use of reflective equipment by scooter riders.

The aim of this paper is to explore factors that influence the use of protective equipment, including helmets and reflective equipment, by e-scooter riders.

2 METHODOLOGY

An online survey of e-scooter riders was undertaken in Australia, Belgium, the Czech Republic, Norway, and Sweden during June to September 2020. Participants aged 18 years and older were recruited by paid Facebook advertising and snowballing. Decision tree models, a non-parametric analysis method, were used to identify factors found to influence the use of various protective equipment by e-scooter riders. Decision trees were estimated for helmet use, fluorescent item/element use, reflective item/element use, and not using any protective equipment when riding e-scooters. All decision trees examined the following factors: gender, age, frequency of e-scooter use, use own or rented e-scooters, perceived level of e-scooter skill among other road users, perceived level of e-scooter skill over rough terrain, and perceived safety of using an e-scooter. The reflective and fluorescent item/element and using no protective equipment decision trees also included the additional factor of what time did your most trip start.

3 RESULTS

The majority of e-scooter riders surveyed (n=1,126) were male (69.6%) under the age of 44 (74.4%), with almost half (49.5%) riding a shared e-scooter on their most recent trip. Almost half (47.4%) believed riding an e-scooter was safe or very safe. More than 80% agreed or strongly agreed that they were confident in their ability to ride near other road users, although their confidence was lower on rough terrain (62.5%). The use of protective equipment was mixed, with many people not using any (see Table 1). The decision tree for self-reported helmet use showed that the strongest factor influencing use was country of residence, and use of a private e-scooter more likely to result in helmet use. There was less use of fluorescent clothing, although use was higher for e-scooter riders in Australia, Belgium or the Czech Republic than for riders in Norway or Sweden, with more frequent riders more likely to wear fluorescent clothing. The factor most associated with self-reported use of retro-reflective clothing was also country of residence, with retro-reflective protective equipment use higher in Australia, Belgium and the Czech Republic and influenced by the perceived ability of riders to handle e-scooters on rough terrain.

Table 1. Reported use of protective gear the last time an e-scooter was used (%)

The last I rode an e-scooter I wore:	Australia (n=329)	Belgium (n=89)	Czech Republic (n=283)	Norway (n=374)	Sweden (n=151)	Total (n=1126)
A helmet	93.0	64.0	37.5	11.2	17.9	43.9
Wrist protection	6.7	14.6	3.9	0.8	0.1	4.1
Elbow protection	5.5	12.4	2.5	0.0	0.0	2.9
Knee protection	4.6	5.6	2.5	0.3	0.0	2.3
Fluorescent jacket/ clothing/ element (eg., backpack, helmet)	14.9	48.3	22.3	6.1	1.3	14.7
Light-reflecting item (e.g., strip on pants/jacket or backpack)	18.5	28.1	39.9	6.1	6.0	18.8
None of the above	5.8	30.3	40.6	81.8	80.1	48.0

4 CONCLUSIONS

E-scooter users are most likely to use them regularly, but not for every trip. Social norms and local regulations, self-perceptions of skills, and perceptions of risk are likely to influence protective behaviour use among e-scooter users. While country of residence, user age, type of e-scooter used (shared or personal), confidence in ability to handle an e-scooter on rough terrain and frequency of use influenced the use of protective equipment, the perceived safety of using e-scooters did not. A multi-faceted approach is required to improve the uptake of safety equipment for e-scooter riders to reduce the risk of crashes occurring and mitigate the severity if crashes do occur.

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Riding an e-scooter at nighttime is more dangerous than at daytime

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Keywords: e-scooter, safety, crash rate, micromobility

1 INTRODUCTION

With rapidly increasing e-scooter usage in the United States [1], a growing number of studies aim to understand the safety aspect of these emerging modes. The existing literature has a limited understanding of time-of-day and seasonal patterns of e-scooter crashes. While many e-scooter safety policies are based on the number of crashes [2, 3], accounting for exposure provides a measure of risk to inform effective preventive strategies [4].

This study focuses on motor-vehicle involved crashes since they constitute the most severe and fatal injuries. We compared daytime and nighttime motor-vehicle involved e-scooter crashes and combined them with micromobility trip data to generate exposure variables and estimate crash risk. The key research question of this paper is as follows:

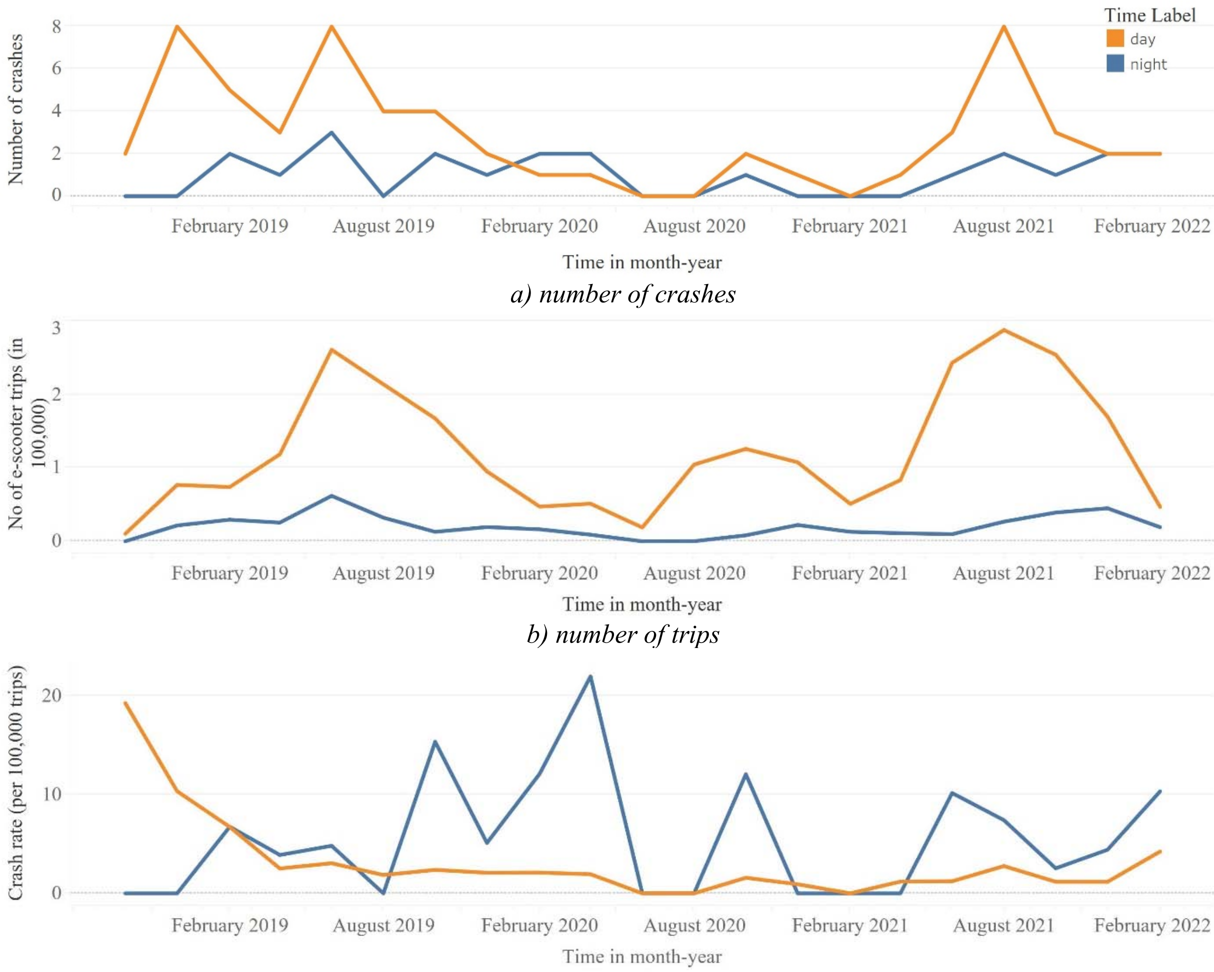
1. Are crashes or crash rates disproportionately higher at night than in the day?

2 METHODS

We combined crash records and e-scooter usage data in Nashville, Tennessee, from September 2018 to January 2022, using the following two datasets: 1) Tennessee Integrated Traffic Analysis Network (TITAN) police crash database to identify 82 motor-vehicle involved e-scooter crashes. We acquired the crash database for September 2018 to February 2020 from the research data of Shah et al. [5] and followed the same data collection processes to complete the dataset for the remaining study period. 2) Shared Urban Mobility Device (SUMD) dataset for e-scooter exposure for September 2018 to February 2020 acquired from the City of Nashville through a data request. We obtained e-scooter trip data for the remaining study duration from Populus Technologies, Inc, which currently curates e-scooter data for the City of Nashville. We also used Astral API to extract dawn and dusk time for a given day to identify the proportion of trips completed and crashes occurring during the daylight and nighttime hours [6].

We received hourly aggregated data from Populus Technologies, Inc with basic data cleaning (a total of 1,758,327 trips for March 2020 to January 2022). We cleaned the SUMD trip dataset from September 2018 to February 2020 following similar criteria as Populus Technologies, Inc. We first removed the duplicate trip records from the SUMD trip summary dataset resulting in 1,703,964 unique trips, and excluded 3% of the records following the cleaning criteria of Populus as follows: 1) trips with less than two or more than 5000 GPS coordinates (less than 1% of records), and 2) trip duration more than 7 hours (3% of records). In addition to these criteria, we also removed 16% of records with trip distances less than 200 feet as they are not likely e-scooter trips. We used 3,162,728 trip records throughout the study period for the analysis.

Figure 1 summarizes the bi-monthly number of crashes, e-scooter trips, and the number of crashes per e-scooter trip (crash rate) segmented by day and night throughout the study period. We used the bi-monthly level of aggregation because some months did not have any daytime or nighttime e-scooter crashes. The number of daytime crashes was generally higher than the number of nighttime crashes, as illustrated in Figure 1 a. The number of daytime trips was also higher than the number of nighttime trips, as illustrated in Figure 1 b. However, nighttime crash rates were generally higher than daytime, as indicated in Figure 1 c.



a) number of crashes

b) number of trips

c) crash rates

Figure 1 Bi-monthly number of e-scooter crashes, trips, and crash rates segmented by day and night

We used negative binomial regression in Stata to evaluate the statistical difference in the daytime and nighttime crash rates, with the number of trips segmented by time as the exposure. It is worth mentioning that Poisson regression is not suitable for this case because the mean and variance of the bi-monthly crash are not equal (1.9 vs. 4.4). The dependent variable is the number of bi-monthly crashes, and the independent variable is a dummy variable indicating nighttime crashes. We added a dummy variable for crashes observed between March 2020 to December 2020 as a control for COVID-19, as travel behavior was disrupted due to pandemic lockdown. We also used dummy variables for bi-monthly observations to control seasonal variation in e-scooter usage.

3 FINDINGS

Out of 82 motor-vehicle involved crashes, 60 (73% of all crashes) occur during the daytime, while 22 (27% of all crashes) occur during the nighttime. On average, we observed 2.6 crashes per 100,000 trips. When segmented by daytime and nighttime, the crash rate during the night was higher than during the daytime (4.8 vs. 2.2 crashes per 100,000 trips).

Table 1 summarizes the negative binomial regression model results of bi-monthly daytime and nighttime e-scooter crash rates. The model is statistically significant, indicated by the probability of LR test statistics (0.053). The pseudo-R-squared value is low (0.096) but expected as the model doesn't have many explanatory variables. The dummy variable for nighttime crashes is significant, indicating that the likelihood of nighttime crashes is 2.010 times greater than daytime crashes, holding the other variables constant in the model and controlling for exposure. The COVID-19 control is also significant, suggesting that the number of crashes decreased by a factor of 0.451 during the pandemic when accounting for exposure.

Table 1 Results of the negative binomial regression of e-scooter crash rates aggregated bi-monthly

Dependent variable: number of crashes	Incidence Rate Ratio (IRR)	Standard Error	p-value
Nighttime crashes (dummy variable)	2.010	0.538	0.009
COVID-19 control (dummy variable)	0.451	0.185	0.053
Constant	4.145	1.274	0.000
Alpha	0.047	0.111	
Model statistics			
Time control	Bi-monthly		
Number of observations	42		
Pseudo R-squared	0.096		
Log-likelihood	13.87		
Probability of LR test	0.053		

Possible reasons that e-scooter rides are riskier at night, at least compared to daytime, could be a) low conspicuity as e-scooters are small and are not equipped with powerful lights, including signaling lights, b) low visibility due to poor lighting of streets that makes it difficult for motor vehicle drivers and e-scooter riders to be aware of their environment. We did not see strong evidence of alcohol impairment in the police crash reports from drivers or scooter riders for the same crash dataset of Shah et al. [5]. Although single-vehicle e-scooter crashes might increase at nighttime (e.g., falls, colliding with objects), such crashes are not as severe as motor-vehicle involved crashes that are responsible for 80% of scooter rider fatalities [3]. The policy implication of the nighttime crash rate being higher than daytime is that additional interventions are required to improve the safety of e-scooter riders at night.

4 CONCLUSIONS

E-scooter crashes, with cars at least, are more likely to occur during the nighttime, as indicated by crash rates estimated from trip count as exposure variables. Over the summer, we are expanding this analysis to explore the built environment, transportation network, and behavioral factors contributing to e-scooter crashes.

Future research can evaluate exposure with rider demographics (gender and age group) and riders' experience (first time vs. regular riders). It is possible, but unknown, if tourists, students, or first-time riders are more prone to crashes with cars. Researchers can also explore crash severity during the day or night as well as compare the crash rates over time.

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Visual attention and speeds of pedestrians, cyclists, and electric scooter riders when using underpass: a field eye tracker experiment

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Keywords: shared space, road safety; micromobility, transport policy, hazardous riding, eye fixations.

1 INTRODUCTION

Cycling and walking are typical forms of local locomotion, especially common in the urban environment. During the last five years, portable electric scooters were developed and quickly gained popularity and, at the same time, generated previously unknown challenges associated with safety [1]. Their users compete with pedestrians and cyclists to occupy the same space [2], which may create conflicts and cause accidents. The balance between the safety of pedestrians and ES riders is still being sought [3], while the legislation process lags behind the rapid emergence and popularity of this new micromobility transportation mode [4, 5].

The aim of this research was a comparison of visual gaze behaviour of cyclists, electric scooter users, and pedestrians passing the same route stretch – a broad busy underpass in city centre. Visual interaction of the test participants with other road users was analysed to understand threats and risks for each of these modes of transport during selection of the path; speeds and behaviour during manoeuvres were also assessed. Differences in perception, depending on the utilized mode of transport, should bring better understanding of their specific needs and may support appropriate regulation. This research work could be considered as an extension of previous study when, in the similar way, behaviours of road-users utilizing a shared road were analysed [6].

2 GENERAL INSTRUCTIONS

2.1 Methodological aspects

For many years, eye tracking has been utilized extensively in various research [7], including applications related to behaviours of cyclists [8 .9] and pedestrians [10, 11]. Despite advances in technology of the equipment, the basic concepts include metrics associated with pupil movements of the test subject: gazes, saccades, fixations, and fixation durations. For this research, equipment based on video recording of combined pupil and corneal reflection, spectacles Tobii Pro Glasses 2 (Tobii AB; Danderyd, Sweden) were utilized.

2.2 Field experiment

Eye tracking technique was used to analyse visual behaviour of 15 young people, each of whom was given the task of following the same quite complex urban path, approximately 1500 m long, using the three evaluated modes of transport. Their gazes and fixations were assessed in detail when they were travelling through an underpass 50 m long as well as stretches of around 75 m before and after that stretch; exemplary cyclist's trajectory is shown in the Figure 1. Besides visual attention, speeds, manoeuvres, and the number of other road users who were overtaken, overtaking, and bypassed were taken into account.

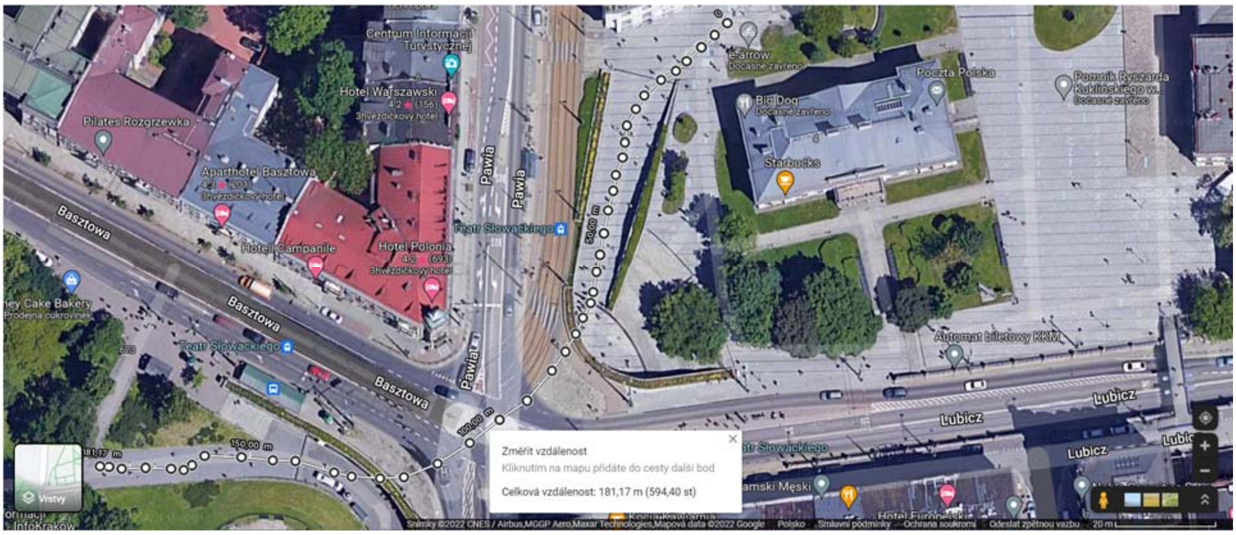

Figure 1: An example of cyclist's trajectory going through the considered underpass.

3 RESULTS EXPECTED

It is anticipated that there would be differences in visual attention depending on the mode of transport. From exemplary data related to distribution of fixations presented in the Table 1, the differences between the transport modes are evident: riders were concentrating their attention on pedestrians, while test participants travelling on foot were more interested in the surroundings. This research of behaviours and visual attention should permit for understanding whether the differences were mainly caused by the interaction between road users and depended only on traffic load, or were also influenced by other factors.

Table 1: Fixations distribution.

Mode of transport	Total number of fixations	Fixations on pedestrians [%]	Fixations on other obstacles [%]
Foot	218	24.8	43.6
Bicycle	194	71.6	7.2
Electric scooter	174	60.3	12.6

4 CONCLUSIONS

Understanding of visual behaviour will bring an important information not only for scientists, but also for engineers involved in designing or re-designing the road infrastructure and for legislators.

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Drivers overtaking cyclists on rural roads: How does visibility affect safety? Results from a naturalistic study

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Keywords: driver behavior, cyclist safety, overtaking, visibility, naturalistic study.

1 INTRODUCTION

Drivers overtaking cyclists on rural roads create a hazardous scenario due to the potentially high impact speeds and, therefore, severe consequences in case of a crash [1]. Díaz Fernández *et al.* analyzed crashes between cyclists and motorized vehicles from various data sources, including insurance reports and crash databases, and concluded that this scenario is particularly dangerous and new safety countermeasures are needed [2].

Other studies have shown that particularly the side-swipe risk through aerodynamic forces due to low lateral clearance and high overtaking speed affects both the objective and subjective safety of the cyclist [3], [4]. Furthermore, recent work by Gildea *et al.* showed through a self-reported survey among cyclists that a significant amount of side-swipe crashes and near-crashes with lower severity of injuries remains unreported [5]. This underlines the importance of investigating further in what situations the side-swipe risk for cyclists increases and how it can be decreased effectively.

Previous research investigated how driver behavior in overtaking is influenced by infrastructural elements such as lane widths [6], road markings [6], [7], parked cars [7], and the presence of road crossings. However, the effect of sight distance on driver behavior has not gained much attention yet. Therefore, this work analyzed the influence of sight distance on driver behavior and the resulting safety implications for the overtaken cyclist.

2 MATERIAL AND METHODS

We collected naturalistic data from smart traffic sensors over seven consecutive days in August and September 2021 on the two-lane rural road Spårhagavägen, south of Gothenburg, Sweden. The investigated road stretch had a speed limit of 70 km/h and consisted of a straight stretch of approximately 150 meters in length with a lane width of about 3.6 m that connects two curve elements. The curve element at the Western end of the observed road stretch was closer to the overtaking locations than at the Eastern end, resulting in a decreased sight distance for drivers. Furthermore, a solid line prohibited overtaking towards the Western end of the road (see the red-shaded area in Figure 1, c).

The data were collected using Viscando's proprietary data collection system consisting of four infrastructure-based sensors OTUS3D[1]. These sensors use 3D vision and artificial intelligence to detect, track, and classify vehicles, cyclists, and pedestrians. Vision data are processed in the embedded computational unit and removed within 20 ms from being captured. Thus, fully anonymous data comprising object positions, velocities, 3D bounding boxes, and road-user types are stored, ensuring full GDPR compliance. The sensors were installed on light posts in a way to cover the whole road stretch in both directions. The object data from all sensors were fused and filtered in post-processing, yielding complete trajectories for vehicles and cyclists on the entire measurement stretch.

[1] Viscando AB (https://viscando.com/, retrieved April 11, 2022).

We identified overtaking maneuvers by the following criteria: 1) a car and a bicycle traveled in the same direction, and 2) there was a passing moment where the car and bicycle were exactly next to each other. We calculated safety metrics such as lateral clearance and overtaking speed at the passing moment. These metrics relate to the objective and perceived safety of the cyclist [3], [4]. Finally, we estimated the driver's sight distance by interpolating a set of manual measurements from Google Maps[2].

3 RESULTS

Analyses from the processing of the measurements resulted in 136 identified overtaking maneuvers, out of which 106 were carried out in the Western direction of the road. We observed that drivers kept less space from the cyclist towards the Western end of the road (Figure 1, b), where the sight distance was shortest. The overtaking speed seemed to decrease in this region, too; however, somewhat less clearly (Figure 1, a). We found that 35 out of the 106 drivers in the Western direction overtook the cyclist during the solid-line segment, and 29 out of 106 crossed the solid line while overtaking (Figure 1, c).

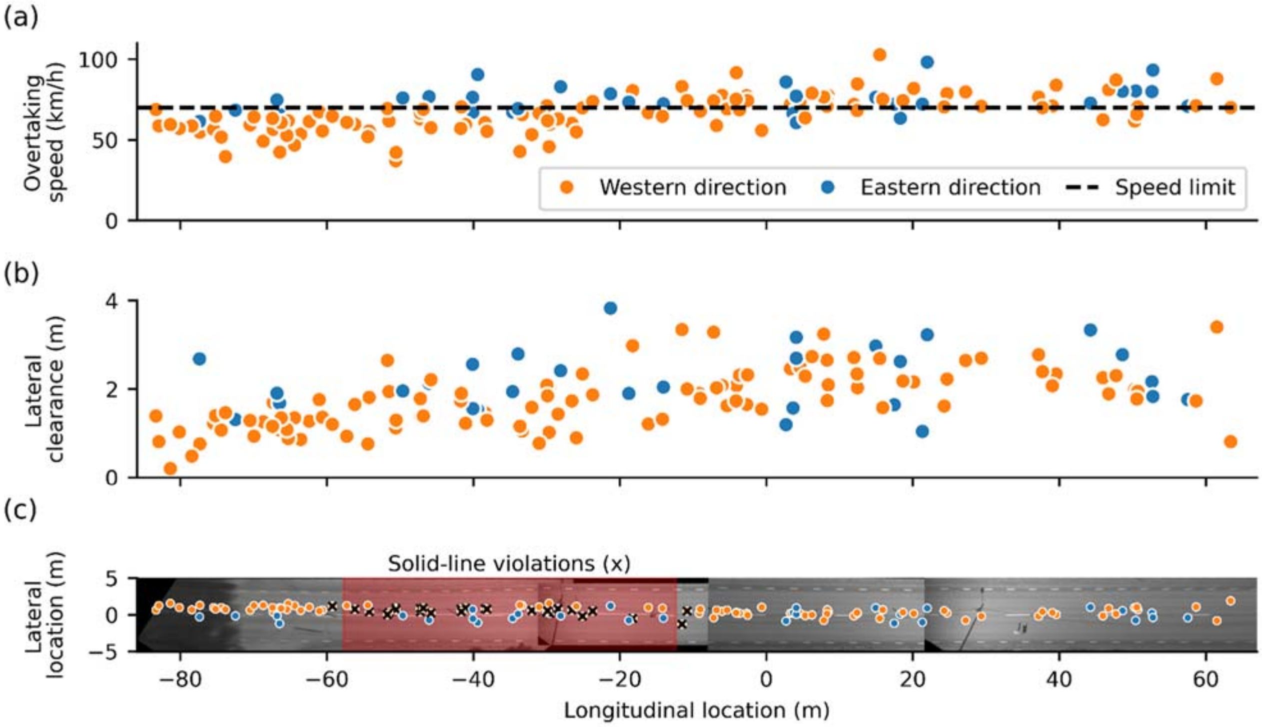

Figure 1: Visualization of all overtaking maneuvers available in the data. Panel (a) shows the overtaking speed of the driver. Panel (b) shows the lateral clearance drivers kept from the cyclist at the passing moment. Panel (c) shows the road locations of the overtaking vehicles at the passing moment, on top of the stitched background images from the cameras of the traffic sensors. Overtaking maneuvers in the Western direction in which the driver crossed the solid line (present in the red-shaded area) are marked with "x."

4 DISCUSSION

Our results suggest that driver behavior is affected by the available sight distance. For example, a curve in proximity reduces the lateral clearance when passing. This effect may be because drivers fear an oncoming car appearing at any moment and, therefore, compromise their lateral clearance to the cyclist to complete the maneuver in less time and with minimal invasion of the adjacent lane.

[2] Google Maps (https://www.google.com/maps, retrieved April 11, 2022).

Some drivers violated the solid line during the overtaking. We assume that the solid line enabled safer overtaking from the driver's perspective, i.e., reducing the risk of a collision with the oncoming traffic. However, it might have amplified the threat to the cyclist's safety by promoting even closer overtaking. This finding is in line with previous research investigating the influence of solid lines [8], [9].

These findings suggest that cyclists may need to be better protected from motorized traffic, especially at locations with low visibility for drivers, for instance, by providing more shoulder space or separated bike lanes. At the same time, overtaking maneuvers should be ensured to follow recommendations on both objective and subjective safety of the cyclist, for instance, through traffic regulations, law enforcement, or active-safety systems for motorized vehicles. Such systems should aim at preventing drivers from overtaking in situations with decreased visibility or during segments where regulations forbid exiting the lane, for instance, due to solid lines. The recorded data set can be helpful for fitting and validating driver-behavior models to improve active-safety systems and enable counterfactual simulations of such systems.

In future work, we aim to fit statistical models to quantify and predict the effects of the sight distance on the safety metrics.

5 CONCLUSION

Drivers may sacrifice the lateral clearance to the cyclist during an overtaking with limited visibility. This effect, demonstrated through naturalistic measurements, may result in decreased safety of cyclists at specific locations. Focused measures at such locations may therefore have an increased effect on reducing the number of crashes and increasing the perceived safety of cyclists.

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Passing distance, speed and perceived risks to the cyclist and driver in passing events

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1 INTRODUCTION

Many studies have examined the level of risk perceived by cyclists when they are being passed by motor vehicles (e.g., Beck et al., 2021; Rasch et al., 2022) and others have reported that drivers with negative attitudes towards cyclists self-report higher levels of driver aggression towards cyclists (e.g., Delbosc et al., 2019; Fruhen & Flin, 2015; Haworth et al., 2018). However, self-reported behaviours may not reflect a driver's observable behaviour (Fruhen et al., 2019). Lamondia and Duthie (2012) proposed that LPD is an indicator of the driver's degree of respect for a cyclist but other driver factors may also be important. Little is known about how accurately drivers can judge lateral passing distance (Haworth et al., 2018) or whether some unsafe passes could simply reflect poor driver understanding of cyclist needs when sharing roadways. The general finding that LPDs are lower when there are parked cars or oncoming vehicles (Rubie et al., 2020), suggests that drivers may leave inadequate LPDs if they perceive that moving into the opposite side of the road poses a risk to themselves or their vehicle. Rasch et al. (2022) is one of the few studies to measure drivers' perceptions of the risk to themselves in overtaking cyclists. Some studies have examined how different motor vehicle speeds influence perceived risk of the passing motor vehicle for cyclists (Apasnore et al., 2017; Garcia et al., 2020; Llorca et al., 2017; Rasch et al., 2022) or drivers (Rasch et al., 2022), generally finding that cyclists perceive higher motor vehicle speeds are more hazardous.

This paper examines (1) whether negative attitudes towards cyclists influence perceptions of risk to the cyclist in passing events, (2) the factors associated with driver perceptions of the risk to themselves, and (3) if increases in motor vehicle speed are associated with higher levels of perceived risk to the cyclist and driver in the passing event.

2 METHOD

This study used video clips of passing events to provide participants with contextual information needed to convey the riskiness of the event. All participants were licensed drivers - 241 were "cyclists" who reported having ridden a bicycle in the last 12 months and 71 were "drivers" who had not ridden during this period. The 24 test videos depicted fast and slow passes and close and far passes at a low speed and a high speed site (speed limits 40 km/h 70 km/h, respectively). After watching each clip, the participant judged the passing distance from 1= definitely less than 1 metre to 4 = definitely more than 1 metre (1.5 metres for the high speed road, the legal minima), how safe the passing event was for the cyclist, and how safe the passing event was for the driver (both from 1 = very unsafe to 4 = very safe). These questions were followed by the Attitudes to Cyclists Scale (ATCS) (Rissel et al., 2002). Binary logistic GEE models examined the impact of road and traffic and participant factors on safety ratings and distance judgements and to account for repeated measures. Non-significant variables were eliminated using a backward stepwise approach to develop final models.

3 RESULTS AND DISCUSSION

The mean age of participants was 47 years (SD=12) and over 88% had held a driver's licence for over 10 years. Only 18% of cyclist participants were female, representative of cyclists in Queensland, Australia, where the research was conducted. Drivers scored significantly poorer on the ATCS than cyclists (means 30.73 vs 34.85, p = .001). Judged LPDs were highly correlated with safety ratings (rs = 0.7, $p < .001$) but did not differ significantly between cyclist and driver participants ($p = .421$). When passing distance judgements were dichotomised to correct or incorrect, accuracy was greater for passes at the high-speed than the low-speed site (78% versus 66%). Despite no difference in accuracy, cyclist participants were significantly more confident in their ability to judge LPD when driving past cyclists than were driver participants (χ^2 (5) = 43.12, p = 0.000).

3.1 Perceived risk for the cyclist

For every metre increase in actual LPD, the likelihood of judging the pass as unsafe for the cyclist decreased by 94% (OR: 0.06, 95% CI: 0.05- 0.08) for the low-speed site, and by 88% for the high-speed site (OR: 0.12, 95% CI: 0.09- 0.15). Judged LPD was also a strong predictor of perceived safety. For every 1 km/h increase in motor vehicle speed, the likelihood of the pass being rated unsafe increased by 6% (OR: 1.06, 95% CI: 1.04- 1.07) for the low-speed site, and 2% for the high-speed site (OR: 1.02, 95% CI: 1.01- 1.03). Cyclist participants were more likely to rate the pass as unsafe for the portrayed cyclist at both sites (low speed: OR = 1.58, 95% CI: 1.06- 2.36; high speed: OR = 1.68, 95% CI: 1.08, 2.62) than driver participants. The presence of parked vehicles increased the odds that the pass would be rated as unsafe for the portrayed cyclist (low speed: OR = 2.26, 95% CI: 1.89- 2.69; high speed: OR = 2.49, CI: 2.03- 3.07). Oncoming vehicles increased the odds of the pass being rated as unsafe for the portrayed cyclist at the low-speed site only (OR = 1.61, 95% CI: 1.38- 1.86).

3.2 Perceived risk for the driver

Female participants were significantly more likely to rate the pass as unsafe for the portrayed driver at both sites (low-speed: OR = 2.43, 95% CI: 1.74- 3.39; high-speed: OR = 2.64, 95% CI: 1.83- 3.82). No other participant factors were significant (including agreeing that it is difficult to judge the distance to cyclist when driving, attitudes towards cyclists, being a cyclist or how often the participant passes a cyclist when driving). For every metre increase in LPD, the likelihood of judging the pass as unsafe for the passing driver decreased by 85% at the low-speed site (OR: 0.15, 95% CI: 0.11- 0.22) and by 62% at the high-speed site (OR: 0.38, 95% CI: 0.26- 0.56). When the pass was judged as definitely less than 1 metre (compared to definitely more than 1 metre) the odds of judging the pass as unsafe for the driver was significantly higher (low-speed: OR = 4.25, 95% CI: 2.43- 7.45; high-speed: OR = 4.25 (95% CI: 2.43- 7.45). For every 1 km/h increase in motor vehicle speed, the likelihood of the pass being rated unsafe for the driver increased by 6% (OR: 1.06, 95% CI: 1.04- 1.07) for the low-speed site, and 1% for the high-speed site (OR: 1.01, 95% CI: 1.01- 1.03). For both sites, a parked vehicle was a significant predictor of rating the pass as unsafe for the passing driver (low-speed: OR = 2.28, 95% CI: 1.92- 2.71; high-speed: OR = 2.34, 95% CI: 1.63- 2.55). Oncoming or adjacent vehicles were also significant predictors of rating the pass as unsafe for the passing driver for both sites.

3.3 Discussion

Consistent with earlier studies, non-cyclist drivers had poorer attitudes towards cyclists than cyclist-drivers. Yet these poorer attitudes did not lead to higher safety ratings (lower perceived risk for the cyclist). This finding was unexpected since past research (where the range of ATCS scores was similar to the current study) found negative attitudes were related to self-reported aggressive behaviour towards cyclists (Delbosc et al., 2019; Fruhen et al., 2019; Fruhen & Flin, 2015; Rissel et al., 2002).

The factors influencing perceived risk to the cyclist and to the driver were largely the same in direction and magnitude (actual and judged LPD, increased motor vehicle speed and the presence of parked vehicles). However, being a cyclist led to higher perceived risk to the cyclist, but had no effect on perceptions of risk to the driver. Female drivers perceived a greater risk to themselves than male drivers did in passing cyclists, but participant gender had no influence on perceived risk to the cyclists. These findings warrant further investigation. The strong relationship between judged LPD and safety ratings may have been partly due to the survey design where participants were asked the distance directly before giving safety judgements. However, it is interesting that the relationship was weaker for the high-speed site.

The results showed that faster motor vehicle speeds were associated with higher perceived risk of the pass for the portrayed cyclist, similar to previous research (Llorca et al., 2017; Apasnore et al., 2017). In addition, faster motor vehicle speeds were associated with higher perceived risk of the pass for the portrayed driver as well, in contrast with Rasch et al (2022) who found that drivers' perceived safety was influenced only by oncoming vehicles with a low time-to-collision.

4 CONCLUSIONS

These findings confirm that while LPD is an important determinant of perceived risk to both the cyclist and the driver, it is not the only factor that increases perceived risk of passing events for cyclists and that motor vehicle speed should therefore be incorporated as part of safe bicycle passing laws.

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Decreasing Automobile Collisions with Cyclists in the United States by Increasing Automobile Driver Awareness

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Keywords: cycle fatality, peripheral selection, foveal analysis, vehicle accident prevention.

1 INTRODUCTION

A significant proportion of automobile collisions with cyclists occur because automobile drivers do not see the cyclists until too late to prevent an accident. In the United States, despite years of flawed utilization of traffic safety technology and procedures and waning interest in the increase in traffic fatalities, cyclists remain very vulnerable, with little improvement in safety on the road, and they are dying preventable deaths. For example, even though Americans drove less in 2020 during the Pandemic, fatalities of cyclists on the road in the United States increased five percent to 891 in that year [1].

Why is it worth studying the subject of decreasing cycle crashes with automobiles to decrease the mortality and disability of cyclists in the United States? I believe it is more than a casual attitude toward cycle safety on the driver's part but a general attitudinal malaise to traffic safety on the part of the American public. The United States had 38,680 fatalities on the road in 2020, up from 7.2% of fatalities in 2019 [2]. By contrast, the European Commission reported that 18,800 people were killed on the road, a decrease of 17% from 2019, making Europe the safest region in the world in traffic safety [3]. There has been almost no awareness of this on the part of the public, nor has there been a public outcry in the United States. The only way that cyclists can increase their chances of surviving on the road is to proactively take action to make themselves more visible to motorists because, according to Laurie Beck, an epidemiologist from the Centers for Disease Control and Prevention, "Nationwide, you're more than twice as likely to die while riding a bike than riding a car, per trip," in the United States [4].

2 GENERAL

The safety issues of low conspicuity and high vulnerability are common factors for cyclists. A significant proportion of automobile collisions with cycles occur because automobile drivers do not see the cyclists until too late to prevent an accident. Even without the numerous distractions that beset drivers today (talking on a cell phone, texting, etc.), it is sometimes challenging for automobile drivers to be constantly aware of motorcycles and cycles sharing the same road. One theory is that motorists who do not have much experience with cycles incorporated as part of their experiential knowledge do not expect to see cyclists. Hence, when they encounter cyclists on the road, these drivers 'look but fail to see' cyclists [5].

The conventional wisdom has been that when a car driver's eyes focus on the road (foveal analysis), they cannot process peripheral information (peripheral selection). However, recent studies have shown that the brain not only processes foveal analysis and peripheral selection simultaneously, but can do it very effectively in parallel and independently [6].

Colors (primarily fluorescent) have been used to increase cyclists' visibility to drivers on the road in the past. There have not been many studies that objectively measure the effectiveness of using fluorescent colors, and few studies have investigated how other common colors could effectively be used to increase cyclists' visibility. I conducted a research study to determine whether car drivers' peripheral selection can be stimulated to help them notice cyclists on the road by assessing which colors worn by cyclists on the upper body and helmet make them more visible.

3 RESEARCH QUESTION

Can the color of a cyclist's clothing influence the reaction time it takes to be seen by motorists, and if so, do some colors require less reaction time?

4 METHODS

4.1 Participants

A total of 487 participants (age 16–75, both male and female) were recruited for the study. The overwhelming majority were volunteers from social media sites such as Facebook and Reddit and were from 37 different countries, of which 75% were from the UK or the US. About 90% had driving experience with a car.

4.2 Design and Procedure

In this study, a GoPro video was made from an auto driver's point of view approaching a cyclist from the rear, approaching from the front, approaching an intersection with a cyclist on the right intersecting the street, and from a car exiting a driveway onto a road with the cyclist approaching from the left. The cyclist that was recorded on video wore each of five combinations of colors in each sequence. The combinations used were street clothes with gray hat, fluorescent upper body with fluorescent helmet, red upper body and red helmet, white upper body and white helmet, and black upper body and black helmet.

After watching and stopping the video of each cyclist when first seen wearing a different color, the participants' reaction time was then recorded to determine how long it took to see the cyclist when each color was presented. The reaction time results were then compiled to determine if there was any pattern of colors representing the least reaction time required to spot a bicyclist on the road.

5 RESULTS

Four ANOVA models were run to assess whether there were significant differences in the mean reaction times for each color based on the direction from which the bicyclist was approached by the driver. The results showed that when the driver approached the bicyclist from the front, white (3.24 s mean reaction time) was the most superior color for visibility, as it had the lowest mean reaction time compared to fluorescent colors (5.16 s mean reaction time), with a difference of 1.92 s. When a car intersected with a bicyclist on the right, white (2.17 s mean reaction time) was a superior color for visibility compared to black (3.16 s mean reaction time), with a difference of 1.00 s. With the car approaching the bicyclist from the rear, white (3.05 s mean reaction time) still maintained a superior mean reaction time compared to red (3.89 s mean reaction time), with a difference of 0.84 s. From the side street on the left, fluorescent (2.57 s mean reaction time) was the superior color compared to street clothes (4.20 s mean reaction time), with a difference of 1.63 s.

Position	Mean Reaction Time					F-Stat	P-Value
	Black	Red	Street Clothes	White	Fluorescent		
Approaching from front	4.01	4.25	4.36	3.24	5.16	56.951	$<2.2 \times 10^{-16}$
Intersection on right	3.16	2.47	2.29	2.17	2.38	24.623	$<2.2 \times 10^{-16}$
Coming from rear	3.52	3.89	3.67	3.05	3.59	12.488	4.671×10^{-10}
Side street on left	3.49	2.84	4.20	3.40	2.57	40.461	$<2.2 \times 10^{-16}$

6 CONCLUSION

The study results showed that the color of the cyclists' clothing and color helmet did have an influence on the reaction time it took for automobile drivers to see them on the road and that some colors required less reaction time than others. The color white had the least reaction time in three of the four scenarios studied. White came in third in the fourth scenario, with fluorescent yellow emerging as the number one color. Overall, white, being the first in three scenarios and placing third in the fourth scenario, could be utilized as the best available color in affording the highest degree of visibility to drivers.

This study was intended to be a real-world study to identify "safer" colors that are affordable, readily available, and culturally acceptable and could be used by cyclists not only in the United States but in any region of the world with high traffic fatalities. The results could assist in policy interventions to decrease cycle crashes with automobiles, hence reducing fatalities.

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Frequency and Legitimacy of Aggressive Driver Behaviour against Cyclists when Sharing the Road.

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Keywords: cyclists, drivers, aggression, overtaking, sharing the road.

1 INTRODUCTION

Cyclists' perception of car drivers as "aggressive" and potentially dangerous is an important reason why they demand dedicated cycling infrastructure or cycle on the footpath even when it is illegal. Cycling infrastructure is built on main roads only. On minor roads cyclists and drivers share the road which might lead to conflicts. We tried to explore such a situation from the perspective of a car driver who drives behind a cyclist and has no opportunity to overtake with the legal safety margin. In such a situation, drivers have several options to react. The only legal option is to adapt their own speed to the cyclist's speed, wait until there is enough room and overtake then. Some drivers show other reactions which might frighten the cyclist and/or increase the risk of a crash: honking, shouting, close following, close overtaking and others. Cyclists might avoid roads where they made or expect such experiences, cycle on the footpath, cycle in the dooring zone of parking cars. Non-cyclists observing such driver behaviour might decide better not to cycle at all. These reactions work against the political aims to increase the modal share of cycling and walking and improve traffic safety for non-motorized road users.

What are the differences between drivers who perform actions which are aggressive more or less often? Which role do their attitudes and mobility habits play? We expected that drivers who see cyclists on the road as less legitimate perform more aggressive acts [1, Oldmeadow]. We expected a positive correlation between perceived legitimacy of aggressive acts and the frequency of their performance. Road users have different general aims like speed and safety. There are also more situation specific aims like expressing one's anger. We expect that drivers see behaviour which is in accordance with their aims as more legitimate [2, Varet] and show it more often. We expect that car drivers who show more aggressive behaviour blame cyclists more for the situation [3, Pimentel]. We expect that persons who cycle more often behave in a less aggressive manner because they see the situation also from the perspective of the cyclist. Aggressive drivers commit more traffic violations [4, King] and thus have a higher risk of receiving a fine. We expected that persons who report more aggressive behaviour have got more fines for traffic offences.

2 MATERIALS AND METHODS

2.1 Aggressive behaviour

We asked drivers for aggressive behaviour, so we deal with self-reports and can expect that such behaviour might be underreported for reasons of social desirability or reported in a subjectively realistic frequency because the questionnaire was anonymous.

We defined aggressive behaviour of car drivers as behaviour that cyclists might perceive as unfriendly, threatening or as potentially harmful: unfriendly comments, gestures, honking, close following, "playing" with the gas pedal, pushing the cyclist to the roadside. We added two items about overtaking: overtaking immediately (illegal), overtaking as soon as there is enough room (legal). One item assessed legal and non-aggressive behaviour: adjusting the own speed to that of the cyclist. We asked how legitimate the behaviour options are seen, how effective to reach the personal goals of the drivers and how often the drivers show each behaviour.

2.2 Questionnaire

We programmed an online questionnaire with SoSci Survey [5]. We assessed demographic information, mobility habits, and general attitudes. Then we presented a picture that showed a street scene from the perspective of a car driver behind a cyclist. We asked the participants to imagine to be driving behind the cyclist in this situation. Because of oncoming traffic the car driver cannot overtake immediately with the necessary legal passing distance of at least 1.5m (Figure 1). We presented several more or less aggressive behaviour options and asked for their perception in this specific situation.

Figure 1: The situation of the car driver in the questionnaire.

2.3 Participants

The participants whom we included in the analysis were 695 car drivers. Inclusion criteria were that the person had finished the questionnaire and had not more than 10% missing values. Participants who marked that they drove a car at least 1 to 2 times per week were considered to be car drivers. The participants were 546 men, 138 women, 4 persons of diverse gender and 7 persons who provided no information about their gender. Their age was 18 to 85 years, mean age 48.8 years (standard deviation 13.8 years, median 50 years). 28 persons were professional drivers (like bus, taxi), 72 drove often in their job (like craftsperson or nursing service), 276 drove sometimes in their job, 315 never drove in their job.

3 RESULTS

The prerequisite for the study was that the drivers said that they showed aggressive behaviour. This was the case: The drivers said that they show aggressive behaviour - with a low frequency. Close following was the item with the highest reported frequency with 66.3% (461 persons) of the drivers saying that they never or nearly never did it and 0.9% (6 persons) that they did it always or nearly always. The aggression item with the lowest frequency was "push the cyclist to the roadside" with 1 person admitting to do it always or nearly always, 2 seldom and 3 persons sometimes.

We reversed the item on speed adaption and determined the internal consistency of the frequency scale of driver aggression. The item "overtaking as soon as there is enough room" had to be excluded because it reduced the internal consistency. All correlations of this item with the frequencies of the other options were below |.1|. The remaining frequency scale had an internal consistency of Cronbach alpha = .70.

Correlations between frequency and legitimacy of a behaviour option ranged from r = .41 to r = .54, correlations between frequency and effectiveness to reach the personal goals from r = .37 to r = .59; both highest correlations were found for close following.

Drivers with different mobility habits differed in the frequency of reported aggressive behaviour. Persons who drive more often and persons who bike less often reported more frequent aggressive behaviour towards cyclists. Persons who had been fined for a traffic offence within the last 12 months reported more frequent aggressive behaviour than person who had not been fined.

We found significant correlations between self justification, victim blaming and aggressive aims in traffic and the frequency of reported aggression against cyclists. Drivers who knew the correct minimal overtaking distance in built-up areas reported less aggressive behaviour than drivers who do not know it.

4 DISCUSSION AND CONCLUSIONS

The questionnaire assessed drivers' self reported behaviour. Underreporting is likely but in general a low frequency of aggressive driver behaviour is plausible: Also from the cyclist such behaviour is infrequent but might still perceived as threatening.

The scale of aggressive behaviour had a sufficient internal consistency. For further studies it might be worthwhile to add items of more subtle behaviour options with which car drivers show their presence to a cyclist ahead of them.

Persons who cycle more often report less aggressive behaviour towards cyclists. Though social desirability cannot be ruled out this is plausible because they know the situation from the cyclist perspective.

Drivers who report aggressive behaviour towards cyclists consider it as more legitimate and more effective to reach their goals than drivers who do not report such behaviour. The legal minimum passing distance of 1.5m in built-up areas in Germany was a relatively new regulation when the questionnaire was online and had been in the media rather often. Correct knowledge of the rule might show interest in legal behaviour or interest for cyclists' rights. Up to now, there is no enforcement of this rule unless there has been a crash and the driver is caught. Enforcement of the passing distance law might also be clear communication that the only legitimate option is to adapt the speed to the cyclist.

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Subjective Safety of Bicycle Infrastructure at Intersections and Roundabouts

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Keywords: subjective safety, intersections, qualitative research, simulation.

1 INTRODUCTION

Cycling provides individual and societal benefits, such as improved health [1], faster intra-urban commuting [2], lower CO2 emissions [3] and all in all lower societal costs [4] compared to most other traffic modes. However, the national average of the cycling mode share was only around 10% in 2008 and has not increased remarkably ever since [5].
Several studies indicate that the lack of subjective safety may be a crucial reason to refuse using the bicycle [6, 7].While there is evidence on how to improve subjective safety through infrastructure on road sections [8], there is none concerning intersections or roundabouts yet.
To close that gap, we investigate subjective safety at junctions depending on different infrastructure designs.

2 METHOD

Participants (N=48, 54,17% female, M_{age}=44, SD_{age}=16,5) were asked to pass differently designed and simulated junctions followed by focused interviews.

2.1 Junction Design

For the analysis, we selected four different junction designs to be presented to our participants (see Figure 1):

- intersection with cycle lane without offset and without physical separation (German: “Radfahrstreifen”; RFS)
- intersection with cycle lanes between car lanes (German: “Radfahrstreifen in Mittellage”; RiM)
- intersection with cycle path with offset and physical separation (so-called protected intersection; PI)
- roundabout with cycle path with offset and physical separation (German: “Kreisverkehr”; KV).

The designs correspond to current technical regulations [8, 9]. Some parameters represent best practices that are not (yet) part of official infrastructure guidelines, such as the continuously coloured bike lanes [10].

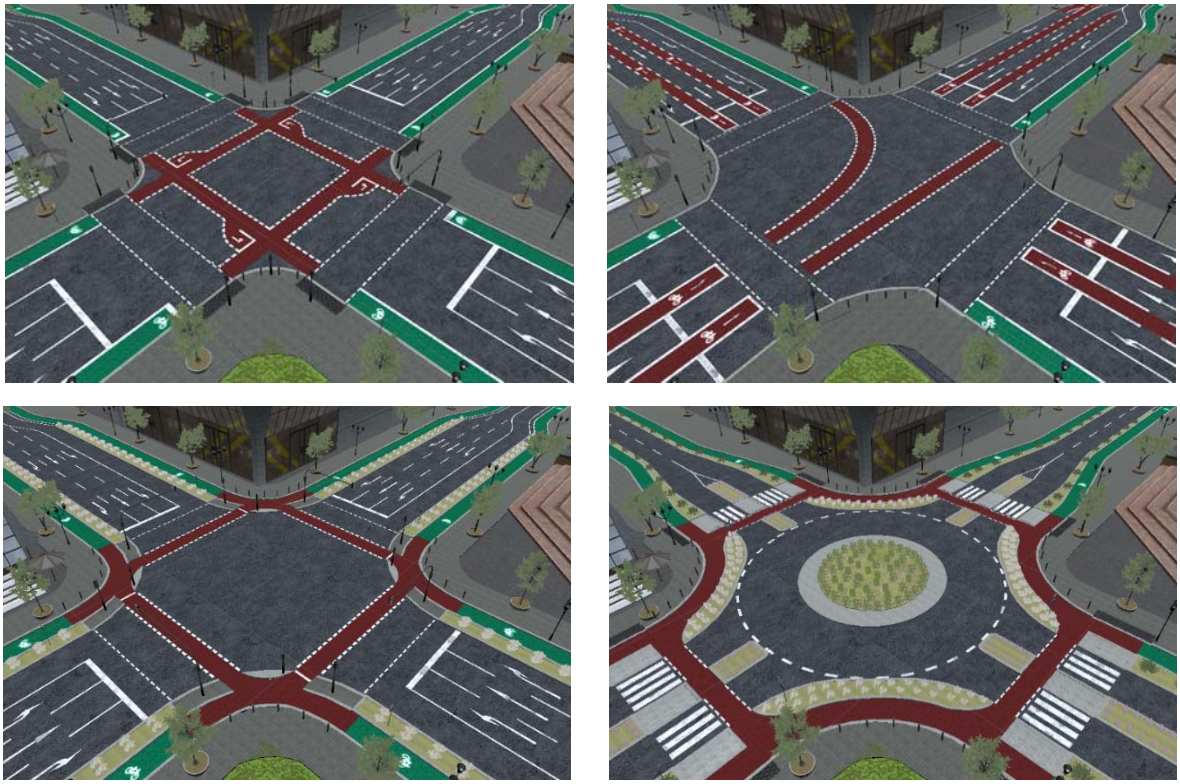

Figure 1: The four junction designs as shown in the simulation (top left: RFS, top right: RiM, bottom left: PI, bottom right: KV)

2.2 Presentation mode

The junction designs were presented in a bicycle simulator that operates in a 360°CAVE (Cave Automatic Virtual Environment). The technical setup of the bicycle simulator comprises measuring the steering angle and rear wheel speed of a stationary bicycle and transferring them via an Arduino to Unity to navigate the participant in the virtual city traffic scene.

2.3 Participants' task

Participants were asked to ride through four different simulated cities. Each city consists of three subsequent identical junctions separated by 75 metres of straight road with a protected bike lane. Participants had to turn right on the first junction, pass straight through the second one and turn left on the third one. After each ride, we conducted a focused interview on this specific junction design.

3 RESULTS

In general, most participants felt safest cycling through the PI design, followed by KV, RFS and RiM. Nevertheless, a few participants preferred RiM to the other designs.
Apart from this general assessment, we will analyse our data in the next months to identify positive and negative aspects for each design. We will present these results at the conference.

4 DISCUSSION

Overall, our results indicate that most cyclists and non-cyclists feel safer and thus prefer to ride with physical separation from motorized traffic on junctions. However, since some cyclists feel uncomfortable with the physical separation, a differentiated approach is needed to design junctions that fit all cyclists.

5 PROSPECTS

To respect this subjective nature of safety perception we will structure and interpret our recent findings, taking into account established cyclist typologies. We already conducted detailed interviews on mobility socialization and cycling behavior that will build the foundation of this analysis.
Furthermore, we will create and test new designs based on the statements of our participants. A multi-disciplinary advisory board will evaluate these designs in the end.

6 FUNDING

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Cyclists' choice of lateral position and feeling of safety between tram tracks, sharrows and parked cars

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Keywords: cycling safety, tram tracks, dooring, sharrows, norms.

1 INTRODUCTION

Cycling is good for the environment, healthy and affordable [1]. However, these benefits are offset by the risk of being involved in traffic crashes [1], with infrastructure characteristics like tram tracks or parked cars increasing aforementioned risk [2, 3]. Bicycle crashes with tram tracks can occur when cyclists turn onto streets with tram tracks or cross them for other reasons, such as avoiding parked cars on the side (oftentimes related to sudden maneuvers to avoid collisions with the door of a parked car being opened) [4]. Such collisions, referred to as *dooring crashes*, account for a significant proportion of bicycle crashes [3]. Nevertheless, the majority of cyclists ride in the so-called dooring zone, which is the area next to parked cars where dooring crashes can occur. If the cyclists' lateral distance to parked cars is large enough, the risk of being involved in a dooring crash can be eliminated [2]. Cyclists' position on the road can be influenced by descriptive norms which reflect a typical or normal behavior: If many other cyclists ride within the dooring zone, then the descriptive norm in this situation is to ride in the dooring zone [5]. People may also ride in the dooring zone because they are convinced that important people around them would approve of this behavior (injunctive norm), e.g. because it is communicated verbally. Apart from influencing cyclists' choice of position through norms, installing bicycle lanes with buffer zones to keep cyclists out of the dooring zone would be a solution. However, particularly in urban areas, a lack of space can make this impossible. Additionally, if tram tracks run on the road, it is not always practical to mark bicycle lanes or protective lanes, especially when there is little space to the right of the outer tram track. In connection with frequent bicycle crashes roads with tram tracks, it is discussed whether cyclists might particularly often ride within the dooring zone there as not to have to cross the tracks [3, 6]. In those cases where marking of bicycle lanes or protective lanes is not feasible due to width or tram track constraints, bicycle pictograms, so-called sharrows, can be marked in the middle of the lane as a measure aimed at encouraging cyclists to choose a position outside of the dooring zone and to increase their perceived safety, another factor influencing the positional choice [2]. To date, a joint experimental variation of the presence of tram tracks, parked cars, and sharrows with the aim of investigating cyclists' position on the road and their feeling of safety has not yet taken place. Two online studies were carried out to address this research gap, with cyclists being asked to indicate their perceived safety and their preferred position on the road based on images of a traffic situation in which the presence of tram tracks, parked cars and sharrows was varied.

2 METHODS

In both studies, convenience samples were recruited, with around two thirds of respondents being male and most cycling at least 4 times a week. In the first study, 1 862 individuals were presented with 20 images (cf. figure 1, left-hand side). Three independent categorical variables were varied as within factors: the type of pictogram (none, simple pictogram, pictogram with arrow above, pictogram with two chevrons above, pictogram with one chevron above and one below), parking (no parking, parking) and the position of the person cycling ahead in the images (0.8 m from the edge, 1.2 m from the edge; referred to as descriptive norm).

Participants were asked to indicate where they would ride by selecting one of 21 yellow lines and to indicate on a 5-point Likert scale how safe they would feel *in the position of the cyclist in front of them*.
In the second study, tram tracks as well as injunctive norms were added as further factors and the number of presented lines was reduced. 3 200 individuals were presented with 8 images (c.f. figure 1, right-hand side). Three independent categorial variables were varied as within factors: tram tracks (no tram tracks, tram tracks), parking (no parking, parking) and sharrows (none, pictogram with two chevrons above). Two independent categorial variables were varied as between-factors: the position of the person cycling ahead in the images (0.6 m from the edge, 1.8 m from the edge; referred to as descriptive norm) and an injunctive norm, communicated by a text (text that stated that cyclists should ride close to the edge; text that stated that cyclists should ride far from the edge). Participants were asked to indicate where they would cycle by selecting one of 8 lines and to indicate on a 5-point Likert scale how safe they would feel were they to cycle *in the depicted traffic situation*. The second study was preregistered (https://doi.org/10.17605/OSF.IO/S7PE6).

Figure 1. Left: Example of one of the trial images used in study 1 (condition pictogram without chevrons, with parking, person cycling ahead in 0.8 m distance from parked cars). Distance between the lines 0.04 m. Right: Example of one of the trial images used in study 2 (condition sharrows, with parking, with tram tracks, person cycling ahead in 0.6 m distance from parked car). Distance between the lines 0.03 m.

3 RESULTS

3.1 Which position did the respondents choose on the road?

As expected, in both studies participants chose a more central position for situations with sharrows than for situations without sharrows. Furthermore, participants chose more central positions in the presence of sharrows compared to no sharrows in both studies. Respondents in both studies were found to choose more central positions when parked cars were present. If the cyclist ahead was depicted in a more central position, respondents in both studies also chose a more central position compared to when the cyclist riding ahead drove further to the right, showing an effect of the descriptive norm. Participants in study 2 who read a text that communicated the injunctive norm that cyclists should ride close to the edge chose a position closer to the edge than those who read a text that communicated the injunctive norm that cyclists should ride in the center of the lane. Unexpectedly, in study 2 the chosen position was significantly farther from the edge for situations with tram tracks than for situations without tram tracks.

3.2 How safe did the respondents say they felt…

… in the position of the person cycling ahead?

In study 1, respondents reported feeling safer were they in the position of the person cycling ahead when there were no cars parked compared to when there were parked cars. In situations with parked cars, women reported feeling safer if they were to cycle in the position of the person cycling ahead than men, whereas for situations without parked cars, the difference between men and women was smaller. Respondents indicated feeling safer in the position of the person cycling ahead when the person was depicted in a more central position rather than closer to edge as well as when pictograms were present compared to no pictograms being present, regardless of the type of pictogram used.

… in the depicted traffic situation? (explorative)

While in the first study, we wanted to know how safe the respondents rated the positional choice another person, namely the depicted person cycling ahead, made, in study 2, we asked about the respondents' feelings of safety for the depicted situation. In situations with tram tracks, participants reported feeling less safe than in situations without tram tracks. The perceived safety was similar for situations with sharrows and for situations without sharrows. For situations with parallel parked cars, the perceived safety was lower than for situations without parallel parked cars. The perceived safety was similar for situations with a cyclist cycling ahead far from the edge and for situations with a cyclist cycling ahead close to the edge.

4 DISCUSSION

The more central positions in the presence of parked cars as well as in the presence of pictograms on the road found in both online studies were confirmed in other field studies as well [8, 9]. Prior to our studies, there had been no research on cyclists' positional choices and perceived safety in traffic situations with tram tracks and sharrows. The fact that cyclists chose more central positions in situations with tram tracks is surprising, as that would mean cycling within the track axis and would require crossing the tracks, which is associated with an increased crash risk [4]. As in other studies, cyclists rated situations without parked cars as safer in the two samples studied compared to situations with parked cars [10]. Our online studies show that in situations with sharrows, cyclists felt safer than in situations without this feature. In field studies, cyclists also rated routes with sharrows as safer [8]. The generalizability of the findings is limited not only by the lack of representativeness of the samples, but also by limitations in the study design. The transferability of findings from online studies to the field (ecological validity) is limited. In surveys, only the intention to perform a certain behavior (in the present case: choosing a certain position when cycling) is measured, but not the actual behavior [11]. It is well established in the literature that an intention does not necessarily lead to the intended behavior [12]. In the future, a repetition of the studies with a more representative sample and as before-and-after studies in the field would be desirable to be able to make statements not only about intentions, but also about actually chosen positions and to be able to test the findings on the feeling of safety in a real traffic context.

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A mixed-methods exploration of the factors affecting bike riding participation in Victoria, Australia

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Keywords: active transport, behavioural science, barriers, qualitative research, safety perception.

1 INTRODUCTION

Participation rates in Australia remain low compared to other international settings, and gross inequities exist in participation, including for women and people living in low socioeconomic areas [1]. In recognition of the health and environmental benefits of increasing cycling participation, governments in Australia are increasing investment in initiatives to increase bicycling [2]. Recent research found that 78% of people in Greater Melbourne (a major Australian metropolitan region) are interested in riding a bike [3]. This demonstrates an opportunity for considerable modal shift to bike riding. There is, however, insufficient knowledge of the barriers to, and enablers of cycling for transport in this context.

Research of barriers and enablers in Australia is very limited, however the majority of what has been conducted has been quantitative research in groups whom are already cyclists. Existing research explores factors affecting cycling for all purposes, potentially overlooking differences in barriers and enablers reported for either riding a bike for transport, or recreational purposes. Further, quantitative studies often present the prevalence of a particular barrier or enabler, without consideration of the strength of how preventative, or encouraging the factor may be.

This has resulted in cycling strategies being largely uninformed by the needs of people who are not current cyclists, and without consideration of the needs of people who ride a bike for transport, compared to recreational riders. To increase cycling participation, it is essential to understand the barriers and enablers of cycling for all people of all ages and abilities, and to understand the nuances of their perception of safety. This requires a mixed-methods approach, with a robust sampling approach, to consider the prevalence and strength of the varying factors that influence people's decision to ride a bike or not. We conducted an online survey and semi-structured interviews with people living in nine selected local government areas across Greater Melbourne.

2 METHODS

We aimed to identify the prevalence and strength of barriers and enablers of cycling, stratified by trip purpose in Greater Melbourne, Australia. Quantitative data were collected through an online survey between November 2021 and February 2022. We recruited adults who lived in one of nine selected local government areas in Greater Melbourne using Council social media platforms and electronic and print newsletters, and targeted advertising. The nine selected local government areas were selected with an aim for representation across previously developed urban typologies. These typologies classified areas of Melbourne based on similar land use, bike infrastructure, and population demographics [1]. The survey included questions regarding demographics, bike ownership and frequency of use and questions regarding barriers and enablers to riding a bike for both transport and recreation. Questions regarding the barriers and enablers people experience for riding a bike were separated by trip purpose, where one set asked people to detail the barriers they experience for riding a bike for transport purposes (for example, commuting), and one set for recreational purposes (for example, exercise). Participants were asked to tick all barriers and that applied to them from a list that was randomised between surveys. If a barrier or enabler was chosen, the participant was then directed to a 3-point Likert scale to indicate the relative strength of that factor. For barriers, this Likert scale was rated from 1 = "deters me a little" to 3 = "completely deters me". The Likert scale for enablers was rated from 1 = "encourages me a little" to 3 = "very much encourages me". Descriptive analysis and chi-squared tests were conducted to identify differences between population groups.

Participant classified as 'Interested but Concerned' and that indicated that they were willing to participate in future research were contacted for a further semi-structured interview. Sampling was stratified by gender and region of residence to enable representation and diversity. The interview guide was informed by the survey findings and the Theoretical Domains Framework [4], with an aim to identify potential drivers for behaviour change. Qualitative data were analysed thematically with an inductive and deductive approach to identify emergent themes and to inform the Theoretical Domains Framework.

3 RESULTS

Of the 912 people who began, 717 completed the survey (79%) and were included in analyses. Age and gender of the sample were representative of the populations selected. However, the sample had a relatively higher income. The majority of the sample (73%) owned a bike, and 64% had ridden a bike in the past 12 months. At the time of writing, 5 out of 40 interviews were complete. All potential participants had indicated that they were interested in riding a bike, rode a bike and would like to ride more or for a different purpose (for example, wanted to ride for transport and currently rode for recreation only).

The most highly reported barriers to riding a bike for transport included not wanting to ride on the road with motor vehicle traffic (56%), concern about collision with a motor vehicle (54%), bad weather (53%) and motorist aggression (53%). Findings were similar for barriers to riding a bike for recreation, however bad weather was the second most highly reported enabler (49%). When interviewed, the majority of people reported issues with quality and consistencies of existing infrastructure that would force them to ride a bike on the road. Many noted this as their major barrier to riding a bike, despite substantial interest. Qualitative exploration identified nuances in quantitative findings on numerous occasions. Many participants that had not reported issues relating to storage of their bike in the survey, expanded in the interview that while they had storage spaces available, these were often inadequate and met the needs of light-weight recreational bikes rather than the diversity of bikes used. Several participants reported discontinuous infrastructure between local government areas and commented that current infrastructure met the needs of local recreational trips only.

The most highly reported enablers to bike riding for transport included having a bike-lane physically separated from motor vehicle traffic or an off-road bike path (66%), to improve physical health (65%) and to reduce environmental impact (57%). Enablers for recreational riding were similar, however the ride being scenic was more highly reported (54%). Qualitative findings supported survey findings, where the majority of participants reported having protective and connected infrastructure as being their ideal intervention to increase their participation. Participants highlighted a need for protective infrastructure that enabled efficient and direct trips for transport purposes, including to local shops, schools and childcare, as well as commuting.

Bike riding being a positive, healthy and sustainable mode was a view shared across all participants in the qualitative study. An emergent theme, however, was that on and off-road infrastructure, types of bikes available, end of trip facilities and wayfinding resources were designed for the needs of solely recreational riders, or able-bodied people using light-weight racing-style bikes.

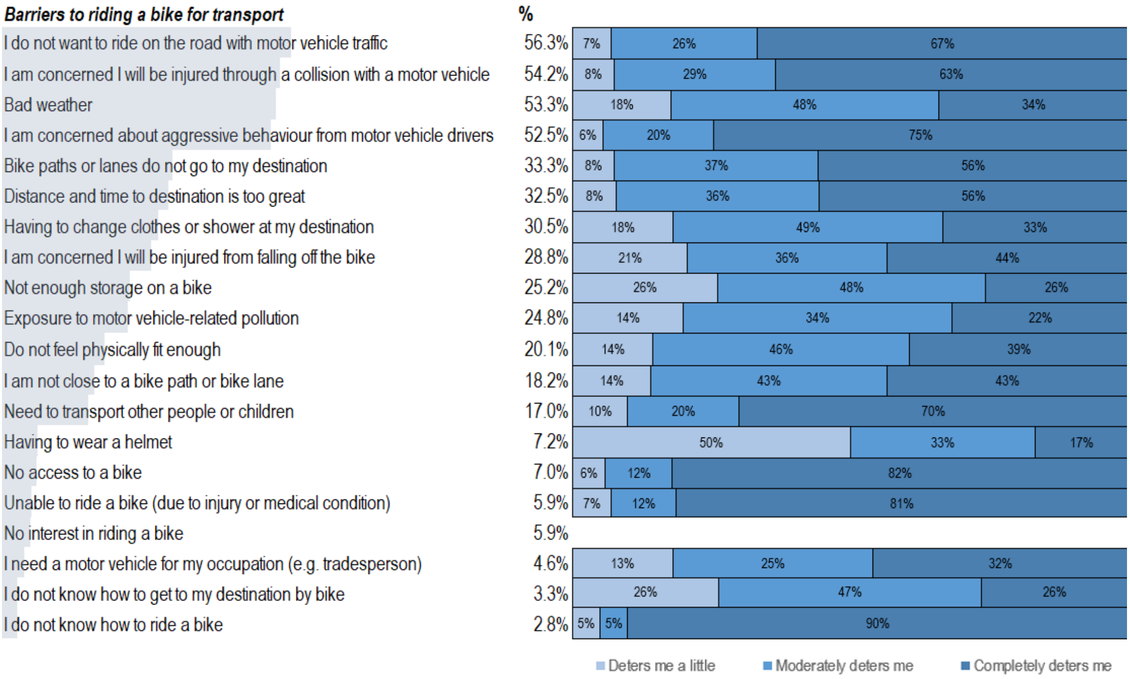

Figure 1. Survey findings: prevalence and strength of barriers to riding a bike for transport

4 CONCLUSIONS

Using a mixed-methods approach, we identified that factors relating to feeling unsafe due to riding a bike on the road alongside motor vehicle traffic are key in preventing people in Greater Melbourne from riding a bike. Participants in the qualitative study thought of bike riding and bike riders as healthy, sustainable and positive. However, they reported that while they wanted to ride a bike, the facilities available to them were inadequate for their needs.

Our results further support the substantial potential for cycling in Greater Melbourne, and identify key infrastructural requirements to enable this. This includes the provision of a network of protected and connected cycle paths to enable efficient transport trips to be made by bike. Other infrastructure measures, such as slow speed areas or diversions through residential streets, may enable supportive links throughout this network. Other facilities and resources, including end of trip services and promotional campaigns, should be designed for the needs and requirements of people of all ages and abilities, and for a diversity of types of bikes. These measures, alongside promotional campaigns to encourage the physical, environmental and mental health benefits of bike riding, may be effective at substantially increasing participation in bike riding across Greater Melbourne.

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The importance of safety on the bicycle friendliness of cities

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Keywords: bike-friendly cities rating, cycling safety, subjective safety.

1 INTRODUCTION AND PURPOSE

In the framework of questions like climate protection, healthy lifestyles and more livable cities it is important to increase cycle use and replace motorized traffic. Safe cycling is one of the preconditions for the growth of cycle use, especially considering the more vulnerable user groups. But how important is safety in relation to other factors influencing bicycle friendliness like comfort of the cycle path and bike parking, accessibility or communication? And how is the relation between 'objective safety' - represented by the number of recorded accidents - and 'subjective safety' as the perceived safety feeling of the bike users?

2 METHOD AND DATA SOURCES

The raised questions can be answered by using data from the ADFC Bike-Friendly Cites Rating (ADFC-Fahrradklima-Test or directly translated Bicycle Climate Test) of the German Cyclists' Federation (ADFC). This survey collects cyclists' perceptions of cycling in their home city or town. Cyclists are regarded as being able to assess their cycling environment because they are "experts by daily experience". Questions include all relevant conditions which have an impact on cycle use. The questionnaire contains twenty-seven assessment questions grouped into five categories as follows: bicycle and traffic climate; value of cycling; safety; comfort; and infrastructure. Everybody who receives the information about the survey, and wishes to respond is invited to participate. There is no selection process (sampling) for acquiring the data. Despite this limitation, the data is generally stable and has proved to be suitable for comparing, monitoring and benchmarking in cities [1]. The roots of the survey can be traced back to 1988. Since 2012 the survey is conducted every two years. Within the 2020 edition of the survey, ratings for 1023 German cities with altogether about 220.000 participants are available. The methodology of the survey had been transferred to several other countries and is meanwhile applied in France, the Netherlands, Czech Republic, Switzerland, Austria, Sweden, Belgium and other countries.

The structure of the questionnaire contains assessment questions in form of a semantic differential: respondents choose a value from a six-point ordinal scale between opposite (positive and negative) statements. The higher the value, the worse the mark. The ADFC Bike-Friendly Cites Rating comprises seven assessment questions within the category of cycling safety (see Table 1).

Table 1: ADFC Bike-Friendly Cities Rating, assessment questions of the cyling safety category

Cycling Safety

In my city		1	2	3	4	5	6	
11.	one feels safe as a cyclist.	O	O	O	O	O	O	one feels vulnerable as a cyclist.
12.	conflicts between cyclists and pedestrians are rare.	O	O	O	O	O	O	there are many conflicts between cyclists and pedestrians.
13.	conflicts between cyclists and cars are rare.	O	O	O	O	O	O	there are many conflicts between cyclists and cars.
14.	there are no obstacles on bicycle paths and	O	O	O	O	O	O	there are many obstacles on bicycle

	bicycle lanes.							paths and bicycle lanes (e.g. traffic signs, lanterns, advertising displays).
15.	bicycle theft is not a big problem.	O	O	O	O	O	O	many bicycles are stolen.
16.	bicycle paths and bicycle lanes are safe and comfortable for cycling, also for old and young.	O	O	O	O	O	O	bicycle paths and bicycle lanes are not safe for cycling, especially for old and young.
17.	one is safe and quick to cycle on roads shared with other road users.	O	O	O	O	O	O	as a cyclist one is under pressure from and hindered by other road users.

These assessment questions can be compared to the overall bicycle friendliness which is measured by the following item:

	1	2	3	4	5	6	
All together, our city is bicycle friendy	O	O	O	O	O	O	All together, our city is not bicycle friendy at all.

Additionally, also the importance of 21 different topics which match with the 27 assessment items had been questioned.

The data of the ADFC Bike-Friendly Cites Rating allows a variety of analytical approaches, e.g. comparing the results of cities, comparing the results of the different questions or correlation analysis of the different questions. Also, the data can be compared to other data sets, e.g data of accident records of the police.

3 SELECTED RESULTS

Within this abstract, a short number of analysis results shall be outlined.

Table 2 shows the correlation of the twenty-seven single assessment questions with the overall bicycle friendliness assessment. Safety feelings determine most of the bicycle friendliness in a city. Also, the feeling of fun while cycling is very much connected to a bicycle friendly city. Both the quality of cycling in mixed traffic as well as off-street-cycling (Riding on bike paths and bike lanes) is very influential for good cycling. Conflicts with motor vehicles determine bicycle friendliness much more than conflicts with pedestrians.

Table 2: Correlation of single assessment questions with the overall bicycle friendliness

	Pearsons correlation		Pearsons correlation
Feeling of safety	0,774	Cleaning of cycle paths	0,534
Cyling as fun or stress	0,712	Control of illegal parking on cycle paths	0,528
Acceptance as road user	0,699	Signposting for cyclists	0,515
Riding on bike paths and bike lanes	0,689	Advertising for cycling	0,501
Bicycle promotion in recent times	0,644	Winter maintenance on cycle paths	0,498
Riding in mixed traffic with motor vehicles	0,643	Media reports	0,496
Width of bike lanes	0,641	Bike parking facilities	0,482
Interruption-free cycling	0,636	Conflicts with pedestrians	0,449
Conflicts with motor vehicles	0,604	Open one-way streets in opposite direction	0,388
Accessibility of the city center	0,586	Cycling by old and young	0,387
Obstacles on cycle paths	0,582	Bicycle transport in public transport	0,318
Surface of the cycle lanes	0,575	Public bicycles	0,237
Guidance at construction sites	0,568	Bicycle theft	0,203
traffic lights for cyclists	0,551		

Figure 1 shows the importance of different topics for cycling. Again, cycling safety proofs to be the most important issue for cycling - in the view of the 220.000 participants assessing their hometowns. The feeling of safety is very much connected to the felt acceptance as road users which is the second most important topic.

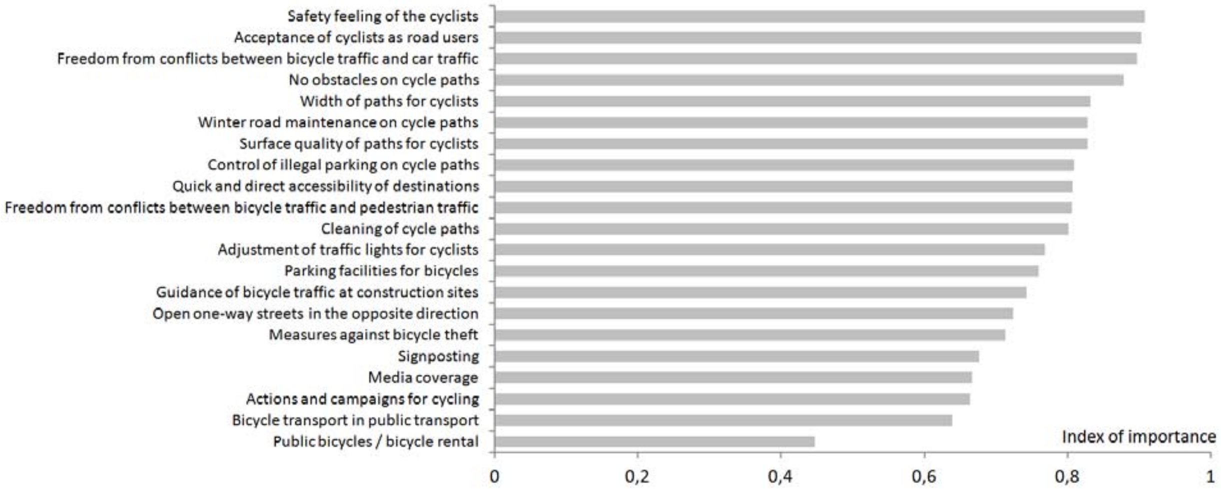

Figure 1: Index of importance regarding cycling for different topics

Figure 2 compares the perceived (subjective) safety from the ADFC Bike-Friendly Cites Rating for different German cities (> 100.000 inhabitants) with the objective data from accident records. The bicycle accidents with injured people [2] were related to the driven kilometer by bicycle extracted from household surveys [3].

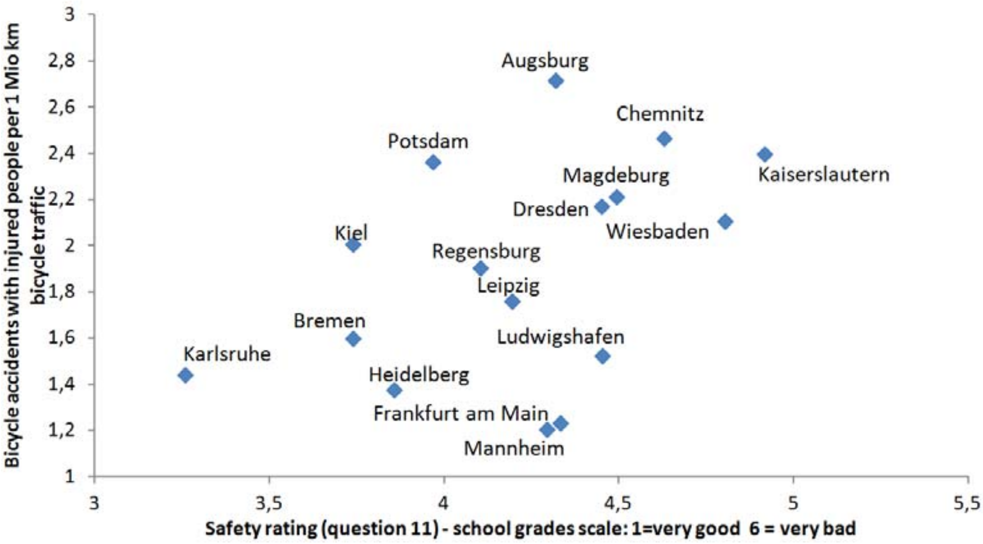

Figure 2: Accident rate vs. assessment of the perceived safety for different German cities

It is clearly visible that the interrelation between indicators of objective and subjective safety exists, but there is still a wide spread between cities which might be due to other factors.

4 CONCLUSIONS

Within the concept of bicycle friendliness of cities, ensuring cycling safety seems to be the most important issue. Interrelation between objective and subjective safety needs further elaboration.

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Perceived cycling safety during Corona times – Results of a longitudinal study in Germany

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Keywords: Cycling, road safety, transport mode choice, sustainable mobility behavior, safety perception.

1 INTRODUCTION

With the beginning of the COVID-19 outbreak and the restrictions put in place to prevent an uncontrolled spread of the virus, the circumstances for daily activities changed. A remarkable shift in the modal split distribution was observed. Cycling was seen as a reliable and resilient option in pandemic times as it allowed social distancing and poses a low risk of contagion. There are detailed studies on the effect of the pandemic on cycling traffic all over the globe which used different data sources, like app data, counters or surveys [1][2]. Apart from the citizens' behavioral responses to the corona pandemic, the municipalities also put up interventions that were meant to support a shift to cycling-based movements in cities. The question to discuss is what changes will be permanent and which changed circumstances, e.g. increased subjective safety, lead to a long-term change of mobility patterns.

The changes in mobility during the COVID-19 pandemic had different impacts on road traffic collisions and road deaths in different countries. While there was a reduction of both indicators in 32 out of 36 countries in April 2020 compared to April 2019, there was an increase in the other four countries [3]. Others also found a reduction of traffic fatalities in 23 out of 24 countries in 2020 compared to a baseline of the previous years (2017-2019), the only exception being Switzerland [4].

The subjective well-being has also changed differently for the different transport modes throughout the pandemic. For example, in April 2020, 9% of respondents said they would feel more comfortable or much more comfortable if they used or would use a bicycle compared to pre-pandemic times; in summer and autumn 2020, this figure was 11%, in spring 2021, it was 13%. In autumn 2021, 15% of respondents said they would feel more comfortable or much more comfortable if they used or would use a bicycle than before the spread of the coronavirus [5].

2 OBJECTIVE

This study aims to assess the safety perception of cycling in Germany, to understand how safety perception changed during and after the restrictions put in place to slow down the pandemic. We want to assess how the different measures influenced the perception and not only compare during the different phases of the pandemic but also compare between the different modes of transport used mainly. We also want to analyze if experienced cyclists or newly started cyclists show different perceptions.

With these results we will come up with conclusions how to use this knowledge to further enhance safety perceptions of cycling in Germany, and beyond.

3 METHODOLOGY

As part of a longitudinal study, several data collection points of a large-scale survey on the topic of mobility during the pandemic allow a detailed analysis of the perceived safety of cycling. The first survey took place in early 2020 right at the beginning of the first lockdown and about 5,000 respondents [2]. We have conducted a second wave of the survey in December 2020/January 2021 with about 1,500 people participating. A third wave was rolled out in April 2022 with a sample size of 1,000 participants.

The respondents were asked to put a personal code in order to be able to combine the three data sets and to see longitudinal effects. Further findings will emerge from the integrated analysis of these analyses which are done in summer 2022. In this way, conclusions can be drawn about the extent to which perceived safety of cycling changed depending on the different conditions during and after different phases of the measures against the spread of COVID-19.

4 RESULTS AND FURTHER ANALYSES

The first step was to analyze the perceived safety of cycling at the time of the first lockdown in early 2020. A sample of 3,364 respondents from Germany was used to record attitudes toward the subjectively perceived safety of road traffic, comparing cycling with other modes of transport. In this first step, the transport modes cycling, driving by car and public transport were investigated. Fig. 1 shows mean values of the modes in question on a scale from 0 (very dangerous) to 100 (very harmless).

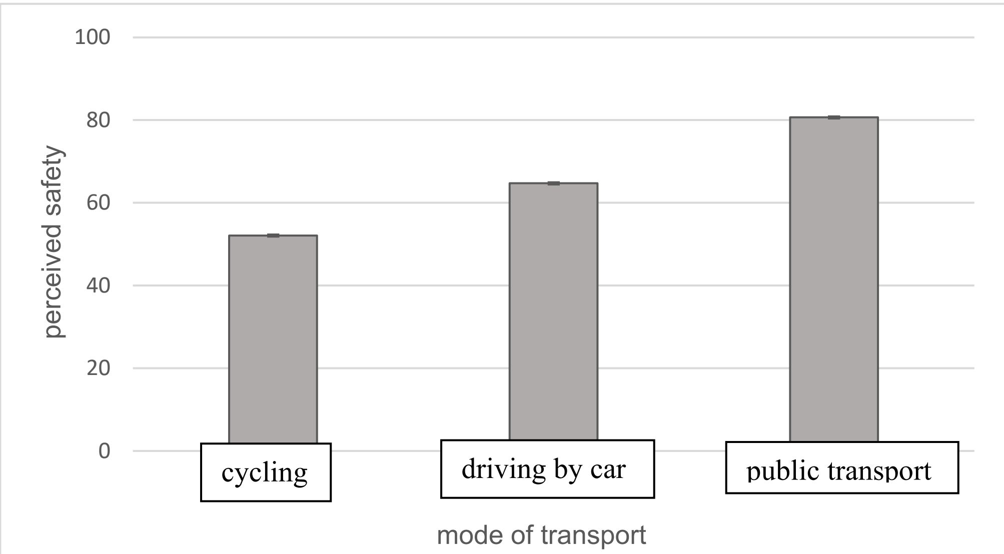

Fig 1. Mean values of perceived safety regarding different modes of transport.

A repeated measures ANOVA (sphericity not assumed: Mauchly-W(2) = .99, $p < .001$) shows that perceived traffic safety in the sample is significantly related to the mode of transport (Huynh-Feldt, $F(1{,}98{,}6653.76) = 829.47$, $p < .001$, $\eta p2 = .20$, $n = 3364$). Bonferroni-corrected pairwise comparisons show that perceived traffic safety is significantly higher for motor vehicles (M = 64.70, SD = 30.80) compared to bicycles (M = 52.08, SD = 29.84). The use of public transportation (M = 80.66, SD = 27.21) is perceived as safer than driving by car and safer than cycling. The effect size f according to Cohen is 0.50, which corresponds to a strong effect [6].

In a second step, it will be investigated to what extent the perceived traffic safety of cycling compared to other traffic options has changed over time. Specifically, because to the different data collection points, this study will be able to compare differences in perceived cycling safety in early spring 2020, early summer 2020, in winter 2021 and spring 2022. In this way, it will be possible to assess whether the perceived cycling safety changed within the first lockdown and how sustainable such an effect might be.

5 PRELIMINARY CONCLUSION

Cycling is one of the environmentally-friendly alternatives to motorized private transport for individual transportation. The mere reduction of cars on the road at the beginning of the first lockdown in 2020 has been enough to alter the safety perception of some people sufficiently enough for them to see cycling as a viable option. The implementation of new bicycle infrastructure also supported this. However, cycling is still seen as a potentially dangerous mode of transport by many. Comparisons from different data collection points will allow conclusions to be drawn regarding the conditions in traffic that lead to perceived safety of cycling and how to promote said cycling safety.

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Cyclists' Safety and Security Multiple Correspondence Analysis from GPS Records for Route Choice in Bogotá - Colombia

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Keywords: cycle infrastructure, mobile applications, stratification of variables.

1 INTRODUCTION

This research analyzes cyclists' route decision by considering attributes of road safety and security from GPS records of a mobile application in Bogotá. The dataset comprises 3016 georeferenced routes of cyclists registered in the Biko mobile application during February 2018. This database was complemented with accident and thefts records from public entities, a descriptive statistical univariate analysis (RStudio), a Multiple Correspondence Analysis –MCA– (Stata), with multivariate statistical approach, and geographic component (QGIS and ArcGIS).

The methods allowed obtaining: [i] a procedure for characterizing quantitative variables per km of route traveled; [ii] Categorization of continuous variables for establishing multivariate relationships through MCA –prerequisite for using this method instead of using surveys (Mobility survey 2019 cyclists' section in Bogotá); [iii] cyclists' commuting patterns with identification of main Origin - Destination zones (UTAM in Bogotá), and [iv] possible initial conditions for the public policies approach in Bogotá, with a continuous comparison between case studies in: Colombia, Latin America, Europe, and the United States, in order to be replicable for any city. Figure 1 exhibits the location where such method was applied before.

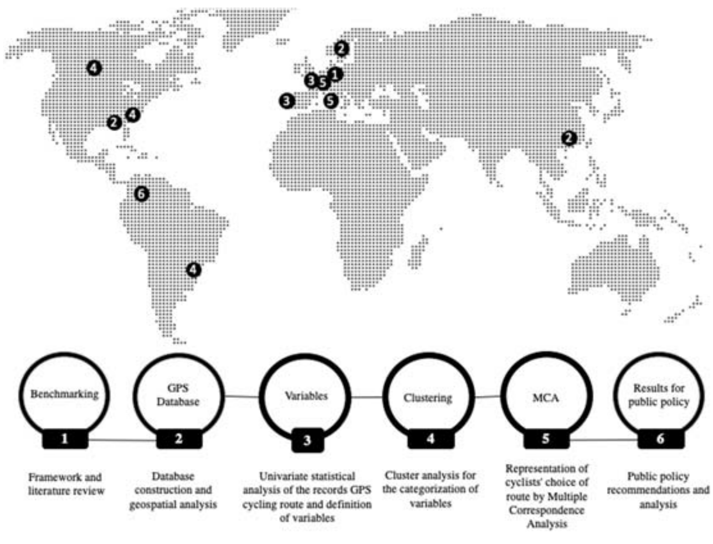

Figure 1. Graphic summary of the investigation

2 LITERATURE REVIEW

At an international level, the systematic review by Pritchard [1] identified that, in the last two decades and with a greater scope of research since 2010, the analysis of bicycle use has focused on the cyclists ' route and their decisions, based on 2,744 publications, allowing dimensioning how the cycling routes have been studied, their importance for the academy and the application of methods in public policies promotion of the bicycle.

3 GPS DATABASE

The geospatial analysis of bicycle routes depends on the origin of the information, usually from mobile applications. Likewise, the monitoring of bicycle routes is no longer limited to traditional sources, such as surveys and trip counts. Strava, a popular fitness tracker, has enriched bicycle research opportunities for the past five years [2]. Moreover, it has been identified that the records on Strava include the total volume of bicycle traffic (number of trips) on the road segments of the network provided [3], which implies a process of disaggregation and treatment of data for the identification of each trip with its respective route, transport analysis zone and Origin-Destination pair. In the case of Bogotá, 3016 GPS routes from the Biko mobile application were used.

4 VARIABLES

The analysis of bicycle traffic accidents helps to detect patterns, such as areas of greater exposure to traffic risk or temporary variations in accidents. Furthermore, it is possible to formulate and prove hypothesis on the road safety of cyclists [4]. In addition, a study on bicycle accident rates for the United States, United Kingdom, Germany, Denmark, and the Netherlands, from 1990 to 2018, evaluated the distance cycled (km), as a measure of the death rate because it reflects the degree of exposure to possible traffic hazards, better than the number of trips or hours on the bike [5]. Therefore, the following section shows the variables we analyzed in this study, looking for the answer to what are the factors that influence the route decision of the cyclists, using the method shown in the introduction.

5 CLUSTERING AND MCA

The Multiple Correspondence Analysis (MCA) requires categorial variables. Therefore, we used k-means function and average distance graph of Silhouette, in RStudio, for identifying the optimal number of clusters for each variable per km of route and performing the categorization in groups (Figure 3). From the Multiple Correspondence Analysis map (such as Figure 2) and for all the variables, we found cycling route patterns by the proximity of the records of the 3016 GPS routes. For example, long length routes corresponded to the three highest speed categories, and most of them at night on Tuesdays and Thursdays without a car. This could be a public policy consistent in supervised cycling route circuits on Tuesday nights, with long lengths, in the existing bike infrastructure with fewer traffic lights in the city.

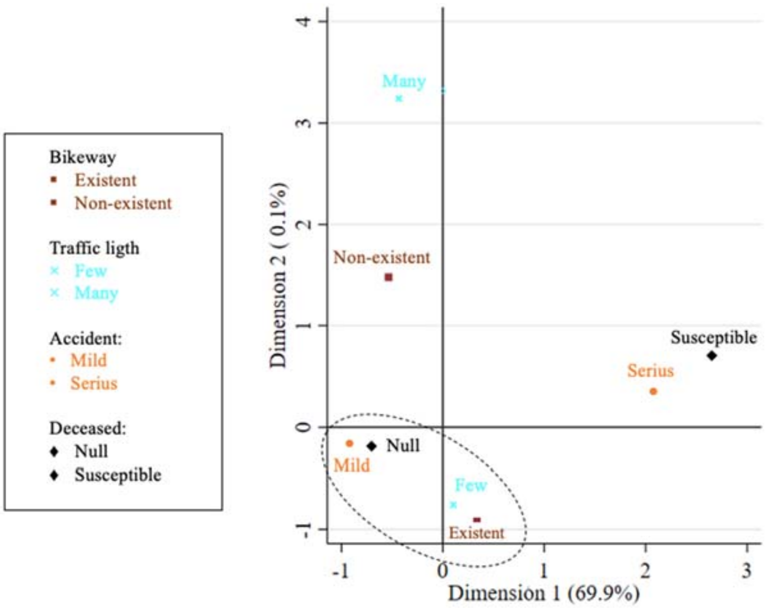

Figure 2. MCA with infrastructure and road safety categories

6 CONCLUSIONS

The main contribution of this research is the procedure supported by a series of methods to analyze cyclists and the variables (Figure 3) that influence their route decision, since could be applied in another city, or in Bogotá, with more recent data from mobile applications, for guiding public policy decision-making in accordance with the availability of information and adaptation of the variables according to the context of each town.

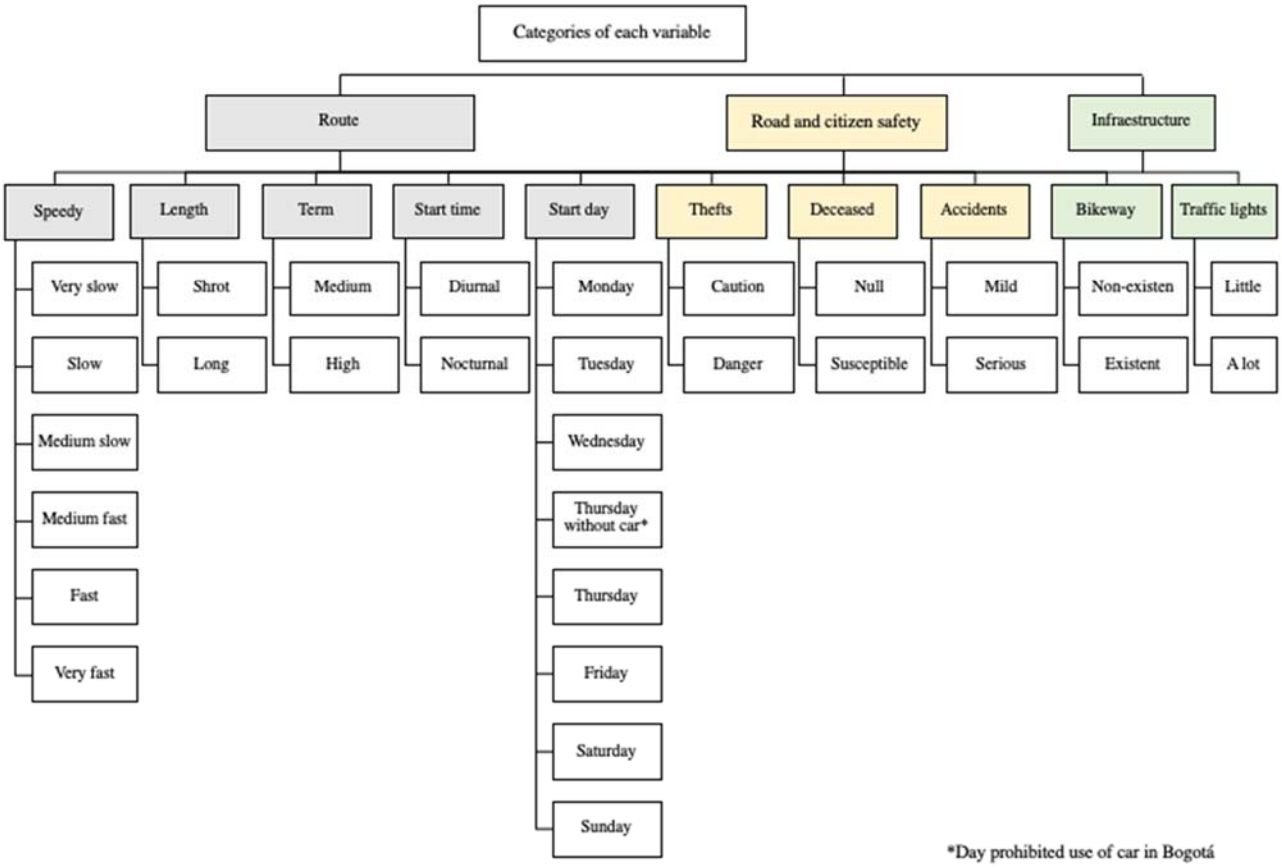

Figure 3. Categories of each variable from cluster analysis

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"The missing lights of Nairobi" -

Cyclists' Perceptions of safety by cycling after-dark in Nairobi, Kenya

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Keywords: Cycling, road safety, NMT infrastructure, sub-Saharan Africa, Kenya.

1 BACKGROUND

Promotion of cycling is important to reach the goals for climate mitigation of the Paris Agreement and Goals of the Agenda 2030. Sustainable transport, both rural and urban, could contribute to at least seven of the 17 Sustainable Development Goals (ITDP 2015). There is relatively little research on cycling in Africa, and there is also much less research on cycling at night. Some studies show the importance of road lighting for minimising the reduction in the numbers of cyclists after-dark and suggest "only a minimal amount of lighting can promote cycling after-dark, making it an attractive mode of transport year-round" (Uttley at el. 2020). So far, these studies have little relation to the situation in developing countries, which is why a first study in Nairobi, Kenya, is carried out here as an example.

In many cities, like in Nairobi, Kenya, cycling is perceived as very dangerous and unsafe partially because there is little respect for cyclists by the operators of the motorized vehicles and there is not much cycling infrastructure. As a result, cyclists have to share the road with motorised vehicles which include trucks, buses, private cars, motorcycles. Hence, cycling is quite a challenge there.

The Kenyan statistics on fatalities are not well defined. The local transport experts declare a high level of underreporting, as well as frequent categorisation of the road crash involving a cyclist under a category of a "pedestrian-related crash". While officially around 3,000 road traffic fatalities are reported, WHO estimates around 13,500 traffic deaths in Kenya (WHO Global Status Report on Road Safety 2018). In addition, according to the official statistics pedestrians accounted for an average of

64.5% of traffic fatalities from 2015-2019, although the number of the registered fatalities among cyclists remain unclear (CDKN 2021). The experts highlight the lack of infrastructure and thus lack of basic safety for cyclists. Cyclists are even defined as "invisible urbanites", as in Kenya "on city streets, various road users, such as pedestrians and cyclists, are invariably excluded" (FES, 2020: 11).

While it is already perceived as dangerous to be cycling during the day, it would be rather imprudent or risky to cycle after sunset in Nairobi. After dark it becomes particularly dangerous, as a disproportionate number of traffic fatalities occur after dark (Plainis 2006), which is a reported tendency worldwide. With a relatively early sunset in Nairobi, differentiating only in minutes, between at about 6:15 pm and 6:50 pm all over the year, which is still a relatively early time of the day, when people can be for example getting back home from their daily activities, the transportation, including cycling, after-dark can be occurring regularly in daily lives of city dwellers. Despite the many safety concerns, there are cyclists in Nairobi. While official data on the number of regular cyclists in Nairobi is missing, estimates from Nairobi's Non Motorized Transport Policy (Nairobi City County Government, 2015) states that from 1.2% to 3% of the capital's population are regular cyclists. With the Nairobi population of about 4.3 million people (Kenya National Bureau of Statistics 2020), the estimated number of regular cycling commuters is from about 52,000 to about 130,000.

As a reference, the "Critical Mass Nairobi" that self-declares as "a group for all the cyclists who would like to see a change in the culture of cycling in Kenya, the availability of infrastructure and equal rights to cyclists on the roads" counts over 7,000 followers (Facebook 2022). The regular monthly rides through the Kenyan capital gather 200-300 riders. The largest gathering counted over 1,000 cyclists. It is reasonable to assume that the number of non-leisure cyclists is many times higher. Naturally, the motives of this underrepresented group are not well understood. There has not been a serious effort of trying to understand transport problems of Nairobi through the lens of this specific group of road users.

2 OBJECTIVE

The study is being conducted in the scope of the research project CAMA, Collaboration on Active Mobility in Africa, with the objective to deliver data on walking and cycling in Kenya, Uganda and Ethiopia, as well as to deepen understanding of the barriers, challenges and opportunities on making active mobility a safer and more attractive mode of transport. The objective of this paper is to demonstrate the cyclists' perception on the features assisting in improvement of cycling safety after-dark in Nairobi, Kenya. With the results we want to give recommendations on how to improve cyclists' safety in such conditions. The example of Nairobi stands as an example for many other comparable cities.

3 METHOD

To answer the research questions a multi-method design is used. In the first step we conducted expert interviews with cycling activists and NGOs in Nairobi, Kenya. The expert interviews established the basis and provided necessary specific information to set up an online survey form to collect data on the cyclists' perception on safety features for cycling after-dark that was shared in different cycling forums. The sample size will consist of a minimum of 50 participants. The survey will include questions towards the usage of the aforementioned safety features such as helmets (and other protective gear), lights and further specially designed equipment. The respondents will have an opportunity to add other, not-mentioned, safety features that they are using. In addition, participants will be asked to rate the personal importance they subscribe to each of these tools for improving their safety. The existing networks of cyclists, including virtual groups, will be contacted to acquire participants for the survey. The evaluation is based on the level of experience of the cyclists and other sociodemographic characteristics. This will provide a first exploratory result on the situation of cyclists after-dark in a Sub-Saharan African country.

4 RESULTS

The online survey will deliver the data on the prioritization of various safety features by cyclists and the importance of certain ones over the others. The survey will indicate the usage of certain tools and the number of respondents perceiving the importance of usage of front lights, back lights, a helmet, a reflective jacket, as well as they will share other safety tools and strategies. However, the importance of prioritization of safe infrastructure cannot be underemphasized.

While experts indicated that simple features such as front and back lamps, a reflective jacket and a helmet contribute to more visibility and thus improve safety of cyclists in Nairobi, these tools have an additional effect on other road users' perception of cyclists in the transport flow. Surprisingly, there is an additional effect of using the said safety features – increase of respect by the boda boda (motorcycle taxi) riders. This tendency is yet to be investigated in an additional study.

5 CONCLUSIONS

The conducted survey is expected to deliver the perspective of the experienced cyclists who are active in cycling networks and can be reached virtually on the subjective importance of safety features being used by them by cycling after-dark. This survey will give an important indication on what are appropriate and necessary safety features for cycling after-dark in Nairobi, Kenya. With the results of our paper, we want to contribute to the research on cycling at a dark time of a day and how the safety of cyclists can be improved.

This preliminary study aims to be the basis for subsequent research into this field. More in-depth face-to-face interviews could provide further insights into the motives of the average cyclists. Likewise, a second study could identify if there is an additional positive safety effect of the safety features through the positive perception of other road participants, particularly, the operators of motorised vehicles.

The recommendation would be, first, to conduct an additional survey involving a face-to-face survey with average cyclists, not only those who can be reached via online media and cyclists' networks. Second, additional study is needed if there is an additional positive safety effect of the safety features through the positive perception of the operators of motorized vehicles as they respect the cyclists using the safety tools at night more than those cyclists who do not. This study must particularly include the perspective of the boda boda riders, drivers of matatus (buses) and of private vehicles.

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Safe or unsafe? - Analysis of policy makers' perceptions on road safety cycling measures.

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Keywords: cycling, road safety, calm traffic, helmet, Ecuador.

1 INTRODUCTION

Urban cycling is gaining popularity worldwide. Inadequate local and international guidelines on street cycling have contributed to a significant increase in road traffic, including increased accidents involving cyclists. In parallel, worldwide, safety data indicates that low-income countries have a high average rate of traffic fatalities (27,5 deaths per 100,000 population), more than three times higher compared to high-income countries (8,3 deaths per 1000.000 population) [1]. Another study found that safety and security factors have not been sufficiently addressed in previous studies regarding bicycle mobility. These factors seem to be more relevant in developing countries than developed ones, and more research is needed [2].

Our study focuses on Ecuador. According to Instituto Nacional de Estadísticas y Censos (INEC), three out of ten households have at least one bicycle nationwide. Still, in Galapagos Islands, six out of each ten homes has at least one bicycle; being the province with the most use of bicycles as transport in the country (16% modal split), which is probably related to the low incidence of crime and less presence of cars in streets in the islands. However, most provinces have medium shares of cycling, e.g. Santa Elena (4.44%), Los Rios (4.32%), El Oro (4%), and Manabí (2,8%) also have a flat geographic surface that might encourage people to cycle, but those are not considered as safe (safety and security). On the other hand, relative safe provinces like Tungurahua (0,61%), Pastaza (0,6%), Esmeraldas (0,54%), Pichincha (0,45%) or Bolivar (0,20%) have very low rates of bicycle commuting [3].

The first National Urban Cyclists Survey [4] was conducted with 2'466 respondents. The survey found three main reasons for people not using bicycles in the city:

- Lack of respect from drivers.
- Lack of bicycle lanes and infrastructure.
- Crime.

Thus, according to this study, more important than status, people perceive safety and security (crime safety) as major barriers to moving by bicycle in the cities in Ecuador.

Further, fatal accidents involving cyclists are an important part of the disease burden attributable to road traffic accidents. These preventable deaths are becoming an increasing health problem, especially among people with poorer health determinants, such as lower levels of education, belonging to an ethnic minority and living in rural areas. The lack of public policies to prevent these types of accidents and the irresponsibility of car and transport vehicle drivers may be linked to the increasingly high proportion of bicycle-related mortality in Ecuador [5].

The Safe Systems Approach (SSA) recognizes that mistakes are always made on the roads; even the best drivers, riders and pedestrians make mistakes or make the wrong decisions. It is up to road safety experts to find a way to avoid accidents, bearing in mind that we are all human [6].

A combination of push and pull measures could change mobility behaviour. It is shown that measures such as car-free zones, 30-kph zones, road diets and other traffic calming measures are likely to achieve relevant improvements for the safety of cyclists. In contrast, the most popular measures to improve cyclist safety among municipal decision-makers are the mandatory use of accessories such as helmets and reflective clothing in Ecuador. Proof of this is that one of the most recent local laws passed in the city of Loja-Ecuador includes, among its paragraphs, fines and traffic penalties for riding without a helmet and without wearing "appropriate clothing"[7]. This highlights a major problem that seems to determine the safety of cyclists, which is the focus of this paper. Those in charge, the municipal technicians or the decision-makers, do not know or do not seem to know what measures to apply in their particular situation. It would be important and necessary for them to identify the proper safety measures and to put them in a place where appropriate.

2 OBJECTIVE

This paper aims to identify a) what road safety measures and policies for bicycles are known to decision-makers, b) how they rate them, and c) which measures could be adopted from the point of view of officials and decision-makers in the main cities of Ecuador. We further want to compare these measures with Germany's road safety and bicycle promotion policies. On the meta-level, with this study, we also aim to raise awareness for the combination of push and pull measures amongst the decision-makers and change their perception if possible.

3 OBJECTIVE

We have planned a data collection through an online survey of at least one administrative representative from each province in Ecuador. Then, a descriptive analysis of the results will identify the measures taken to ensure the safety of cyclists on the roads and the strategies in place for the city to promote bicycle use. The study will be conducted from the perspective of government officials responsible for transport.

The survey includes questions on each representative's academic education, affiliation to an administrative or activist group, experience in road safety issues and, but mainly, perceptions of traditional road safety measures for cyclists and other traffic calming measures used in other developed regions. Finally, it is important to compare these measures and determine whether these measures were applied in German cities and what success they have. Follow up questions close the survey to find out if the knowledge of those measures already changed their perception.

4 RESULTS

The survey results will make it possible to identify the measures to improve road safety that local officials and decision-makers believe are appropriate for the environment. Similarly, it will be possible to determine whether the measures taken in Ecuadorian cities to improve cyclist safety are appropriate and whether these measures encourage the use of bicycles or whether they have become a barrier to the use of bicycles.

In this way, we can also find out whether the use of bicycles remains a sport or a leisure activity for the respondents or whether they are already aware of the potential of bicycles as a means of transport.

Finally, through follow-up questions, we can determine whether respondents have become aware of new ways to improve road safety for cyclists after the survey.

5 CONCLUSIONS

It is likely that the educational background of these municipal officials has nothing to do with transport, mobility or road safety, or that they have no experience or training in these areas.

While it is true that accessories such as helmets, reflective clothing and other accessories that provide safety for cyclists are highly recommended, it is likely that the implementation of calm traffic measures and a systemic approach could achieve better results, not only for the safety of users but also to convince more people to use cycling or other forms of active mobility as a means of transport.

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More than a billion motives to focus on NMT Africa - Enhancing the quality of infrastructure to improve cycling safety and cycling culture in Africa, case in Ethiopia

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Keywords: Cycling, road safety, NMT infrastructure, sub-Saharan Africa, Ethiopia.

1 INTRODUCTION

Urban quality of life is measured by how clean the environment is, how safe people feel, how close they are to green spaces, and in general by the quality of outdoor space. Good quality public spaces are spaces that reduce road accidents through managing appropriately different transport modes, especially walking and cycling [1]. Cycling is healthy, economical, and environmentally sound form of mobility that is fundamental to life. More than one billion of the people in African cities walk or cycle for more than 55 minutes every day - to reach work, home, school, and other essential services [2]. One-third of the population of the African continent uses active mobility as a daily means of transport. This reveals that there is a potential of using cycling as a daily mode of travel in Africa. However, the poor quality of infrastructure for cycling sends a message that cyclists are not welcome in the urban environment. Despite the widespread use of non-motorized modes, transport planning and the provision of infrastructure in most of the cities in Africa have become car-centered, undermining the importance of cycling and walking.

While the majority in the global south are active mobility users, they are not being respected by the public policies and experience 93% of the world's traffic fatalities and injuries [3]. Road traffic accidents are a major cause of deaths and disabilities, particularly in the global south [4]. The traffic accidents and fatalities due to road crashes are not different in Africa. The World Health Organization Global Status report on Road Safety 2018 showed that the African region had 26.6 deaths per 100,000 populations, which is the highest among all regions [5]. Sub-Saharan Africa still has the highest per capita rate of road fatalities of any region in the world. Unfortunately, in most cases, the victims of traffic casualties are primarily pedestrians and cyclists [6]. Much of that is linked to the neglect of the infrastructure needs for pedestrians' and cyclists' safety.

2 OBJECTIVE

The main aim of the study presented is to promote active mobility in the sub-Saharan Africa case in Ethiopia while building on existing activities and combined efforts of applied research to better understand cycling needs. The study aims to assess the existing condition of the cycling infrastructure, understand users' experiences, preferences, and perceptions towards cycling, and come up with viable recommendations appropriate to the context.

3 METHODOLOGY

To achieve these objectives a mixed research methodology (both qualitative and quantitative) are being used. Survey questionnaires, sidewalk bikability audits, and structured and non-structured key informant interviews are being instrumented as a data collection tool. A quantitative data survey will be conducted with 400 participants to better capture the requirements of the cyclists and to illustrate their needs using digital surveys, qualitative interviews, and a crowd mapping approach. The data collection will also take into consideration the needs of special population groups including women, persons with disability, children, and the elderly. The online quantitative survey is planned to be conducted in June 2022. Here we are going to use Addis Ababa as a case study to demonstrate how the improvement of the Non-Motorized Transport (NMT) infrastructure contributes to the improvement of the perception of safety and appreciation by cyclists. This particular case is taken as a best practice and intervention to learn from its strength, examine the existing gaps, and come up with strong approaches and interventions that can improve the safety of cyclists in a similar setting.

4 CASE STUDY AND PRELIMINARY RESULTS ON THE IMPROVEMENT OF CYCLING INFRASTRUCTURE IN ADDIS ABABA, ETHIOPIA

Regardless of the infrastructure challenges and lack of awareness, in recent days transport policy in Africa is starting to recognize the integral role of walking and cycling in any sustainable transport system. Increasingly, African nations and cities are adopting non-motorized transport policies that call for a safe, comfortable, and convenient environment for pedestrians, cyclists, bicycle taxis, and other forms of active transport. One example is Ethiopia's newly published national NMT strategy and the NMT strategy of Addis Ababa city. Nevertheless, there is still a need to better capture the infrastructure requirements of cyclists to demonstrate their needs. Those initiatives are motivating as a starting point to bring a paradigm shift on meeting the infrastructure needs and enhancing infrastructure investments that have been ignored. Cycling is often overlooked in infrastructure financing and cyclists are invisible in most cases.

Under the NMT Strategy for Addis Ababa, the city has dedicated itself to build 100km of cycle lanes over the next three years. The three-kilometer-long *Lebu-Jemo Cycle Corridor* was the first step in this strategy [7]. Before starting the project, a series of surveys were conducted on-site, by the Global Designing Cities Initiative and Addis Ababa Transport Bureau. The results from the survey indicated that 95% of respondents want the cycling corridor to become permanent and 96% of cyclists felt some degree of safety while riding on the interim infrastructure [7].

After the completion of the pilot project, a steady increase in daily cyclists along this corridor was observed. Training grounds are being set up at community centers and schools nearby to further encourage children and their families to cycle as users. Based on the result of the study there are possibilities of instrumenting comparable pilots to upscale similar practical case studies.

5 CONCLUSION

This practical case study clearly illustrates how proper cycling infrastructure can improve the perception of safety and the use of cycling as a mode. This study would like to evaluate/examine the impact of such pilot projects on the safety of cyclists and compare the data on injuries/deaths of cyclists before and after the interventions. Exploring the strengths and assessing the gaps of these projects can help to find out possibilities to scale up such pilot projects in other cities with similar contexts. The study will also help in providing an evidence-based assessment on existing pilot projects that address users' preferences to meet the need of cyclists

The preliminary analysis of the qualitative key informant interview shows that there is a serious challenge in safe infrastructure provision, especially for cycling. Cyclists are invisible due to the lack of proper infrastructure for cyclists. Besides, cyclists are vulnerable to different forms of accidents including road crash fatalities. On the other hand, there is an awareness and policy/strategy at a higher level. The challenge here is the gap on implementing the existing policy and strategies at the operational level. There is poor enforcement of the existing laws and strategies with regard to the provision of a safe cycling environment.

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Challenges and Opportunities in Cycling Safety in Nairobi City, Kenya.

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Keywords: Cyclists, Cycling Infrastructure, Cyclist Safety Perception, Crash Frequency, Risk Factors.

1 INTRODUCTION

The road transport in Kenya is the most common means of transport for people living in both urban and rural areas. The use of bicycles for transport dates back in the pre-colonial time and has been used as a mode of transport until 2008 when the use of motorcycles became a popular mode of travel in the rural and urban areas. However, the use of bicycle as a means of travel has declined consistently over the years until now and many have shifted to the use of car, public transport and most commonly motorcycles which are popularly known as 'boda boda' in Kenya. This modal shift can be attributed to a number of factors identified as challenges in the use of bicycles as a common mode of transport in comparison to other emerging modes of transport both in rural and urban areas. However, despite this modal shift, there are a substantial number of road users who would still prefer to use the bicycle mode amid prevalence in road traffic fatalities and injuries in Kenya. The government of Kenya has established initiatives to provide safe and inclusive transport system by investing in transport infrastructure that includes cycle tracks especially for roads located in the urban cities. This has been enabled by innovation in design, mixed traffic composition, change of legislation and road design standards especially in regards to non-motorized transport in Kenya. Cycling is still low in cities in Kenya despite this effort to improve geometric design of roads. This paper explores these challenges and opportunities in cycling in Kenya focusing on Nairobi city as a case study.

2 LITERATURE REVIEW

Cycling is a mode of transport in most parts of the World including Nairobi City in Kenya. From pre-colonial period, road transport technology has evolved from the use of animal drawn carts, bicycles, motor-vehicles. However, the rate of change of technology has been progressive across the world depending on different stages of development and industrialization in each country. A bicycle was invented in Europe in the 19th century whereby the first bicycle vehicle did not possess pedals. Cycling in Kenya has reduced gradually over the years especially with the advent of motor vehicle technology. There has been a significant mode shift from bicycle to public transport, car and motorcycle respectively in Kenya. In the years before technology, cycling was a primary means of transport for work trips, household trips and recreation activities. This mode of transport was reliable among people of all ages and gender like it is today in European countries.

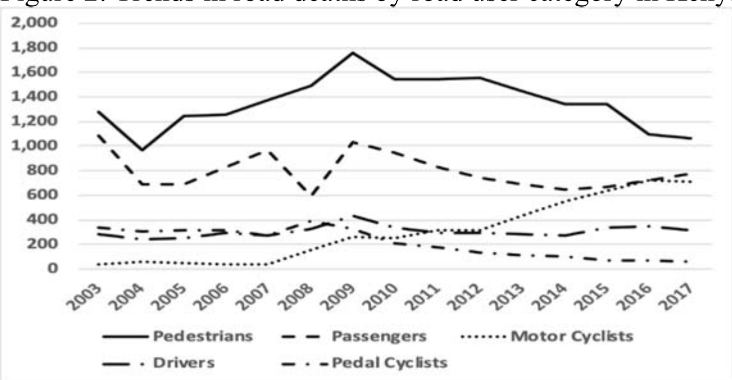
Over the years, cycling has evolved to low numbers and varying patterns among cyclists such as gender, age, physical ability, income levels, size of household and place of residence in Nairobi. Cycling is still considered the fastest means of Non-Motorized Transport (NMT) in Kenya. Cycling bears a great number of benefits including health and physical fitness amongst users, reduced pollution, low cost of purchase and maintenance, low investment in infrastructure, quick connectivity for short distance travel, use in recreation and leisure activities. The government of Kenya has invested in a number of road infrastructure to improve safety of all road users including cyclists by providing infrastructure and space for non-motorized transport in Nairobi.

The burden of road traffic accidents (RTAs) still escalates and bicyclists are not an exception to fatalities and injuries. Most fatal and serious injuries collisions in Nairobi involve pedestrians and cyclists based on accident records across police divisions in Nairobi. The challenges of underreporting is still prevalent and some collisions are still recorded as hit and run with bicyclists involved as victims. This statistics however represents a low population considering the level of deterioration in cycling safety in Nairobi. The use of motor vehicles such as motorcycle, cars, public transport vehicles and commercial vehicles is still dominant in the road transport system in Kenya. Cyclists compete for reduced spaces in the transport system and most commonly along arterial roads in the city. Safety is a function of speed of motion and mass of vehicle involved in collision. Considering low speed and mass of a bicycle in the transport system indicates a higher level of vulnerability in case a crash occurs involving a cyclist and other motorists. Usually the result of such an impact is fatal if not leading to serious injury. The recent surge in economy due to shortage of petroleum fuels for motor-vehicles has sparked interest in the use of bicycles amongst many road users especially for short distance travel. This paper investigates these challenges and opportunities in cycling and recommends best practices for adoption in design and operation of road transport system in Kenya.

2.1 Road Safety Statistics in Kenya

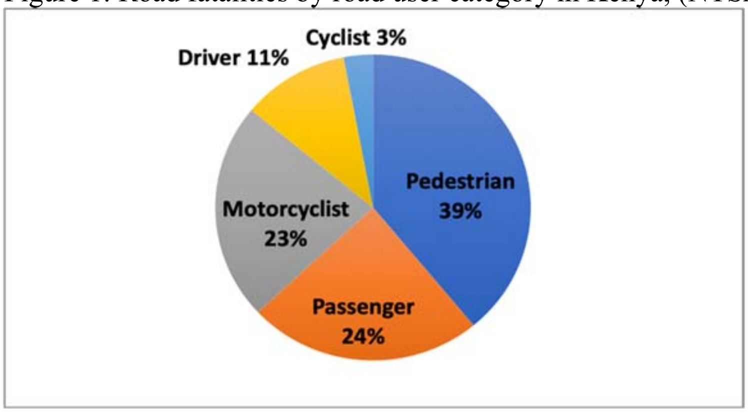
Road traffic fatalities and injuries are still prevalent in Kenya despite measures put in place to curb injuries and fatalities amongst various categories of road users. The decade of action helped Kenya to achieve establishment of the road safety lead agency, increased vehicle safety standards and road safety management. However, more work is still anticipated especially on non-motorized transport (NMT) users such as bicyclists who constitute about 3% of all road deaths in Kenya, [1].

Figure 2: Trends in road deaths by road user category in Kenya (NTSA, 2018)



2.2 Cycling Safety Statistics in Nairobi

Figure 1: Road fatalities by road user category in Kenya, (NTSA, 2018)



2.3 Challenges in Cycling Safety in Nairobi

In Kenya in general, cycling mode of transport is not popular in urban areas and this is evident in the low number of cyclists in the cities such as Nairobi. However, this situation in mode share in the transport system is not by design but could be a factor of a number of challenges facing cycling as a mode of transport in Kenya despite all the advantages it has such as health, reduced emission, low speeds and low maintenance cost and low cost of operation. In Nairobi, cyclists faced a number of challenges such inadequate infrastructure, non-segregated bike lanes, no signal phase for cyclists, inadequate cyclist education on traffic rules, non-marked cyclist routes, lack of policies for cyclists safety and lack of integrated transport plans for terminal and stations which includes parking facilities for cyclists. There are increasing safety concerns for cyclists in the city ranging from speed differentials in the road network, lack of speed calming measures on approach to intersections and junctions, lack of visibility for cyclists, non-helmet wearing rates amongst cyclists and lack of proper designs for bicyclist which could be contrary to human ergonomics. Many cases of road traffic accidents involving cyclists have not been resolved to the best level of satisfaction of the public. A case of an accident involving a student cyclist caused an uproar amongst stakeholders and this attracted the attention of the minister in charge of transport. There is lack of clear reporting for accidents involving cyclists and no follow up on litigation on road accidents involving cyclist as evident in the newspaper article [5].

2.4 Opportunities in Cycling Safety in Nairobi

In the current development trends, the Nairobi Metropolitan services has put considerable measures to improve sustainable modes of transport by building infrastructure for cycling and walking around local streets in Nairobi. Today, there are arterial roads and ring roads whose designs include cycling track and pedestrian walkways for safety. This has been enhanced considering the number of road fatalities and injuries amongst pedestrians and cyclists. According to the National Transport Safety Authority, pedestrians and cyclists contributed to about 40% of all fatalities in Nairobi [2]. Investment in cycling infrastructure will promote cycling amongst all road users, improve health of residents in Nairobi, increase social activities and wellbeing of people in Nairobi. According to many researchers on cycling safety, there is a proposed integrated transport plan which includes pedestrians and cyclists [6]

3 METHODOLOGY

The methodology adopted in this study is a mix of desk study and online opinion survey through questionnaires amongst people living in nine districts in Nairobi such as Westlands, Dagoretti, Kasarani, Langata, Starehe, Kamukunji, Embakasi, Njiru and Makadara. The online questionnaire targets road users of all categories such as drivers, passengers, motorcyclists, pillion passengers, pedestrians and bicyclists.

4 CONCLUSIONS

This paper unveils the opportunities and challenges in cycling safety in Nairobi, a city in a developing country in the global south. It gives an analysis of road users' opinion on cycling safety and compares road users' willingness to shift from the common modes such as use of car and public transport to cycling. It further gives a concise discussion of areas of improvement to promote cycling through improvement in infrastructure, priority for cyclists in traffic management, awareness creation on safety regulations for cyclists, policy formulation for implementation of speed zones for cyclists in residential areas and comparison to international standards on bicycle design for safer cycling.

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Inter- and intraindividual determinants of bicycle helmet use from a health behaviour perspective

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Highlights

- Determinants of wearing a helmet were examined in a cross-sectional study
- PMT, TPB and HAPA were compared using PLS-SEM
- PMT and TPB score well on the model criteria and applicability
- For behavior, intention is the best predictor complemented by planning
- Helmet wearers are also generally more cautious

Keywords: bicycle helmet, protection motivation theory, theory of planned behavior, health action process approach, survey.

1 THEORY

Determinants of wearing a bicycle helmet were examined. Interindividual differences in helmet wearing were formalized with three different health psychological theories. The Protection Motivation Theory (PMT) [1], explains intention for a health behavior using subjective beliefs on the efficacy and costs of a specific health behavior, self-efficacy and risk and severity of negative consequences as well as benefits of not doing said behavior. The Theory of Planned Behavior (TPB) [2] uses attitude, subjective norms and behavioral control about a (health) behavior to predict intention to a behavior, which in turn can predict actual behavior. Lastly, the Health Action Process Approach (HAPA) [3] is similar to PMT, but puts more emphasis on self-efficacy while omitting costs of beneficial behavior. It includes both intention and behavior, as well as planning as an intermediate step between intention and behavior.

2 METHOD

The study was conducted in a cross-sectional way with 889 German-speaking cyclists. Data was acquired using a survey. Items were constructed on a theoretical basis with economy in mind, and responses given on a six-point Likert scale. Participants were recruited using a panel. All models were compared with partial least squares structural equation models (PLS-SEM). Furthermore, the influence of certain conditions on helmet wearing was inquired. The models were used in their original forms and in slightly adjusted versions to compensate for shortcomings identified in PLS-SEM. Criteria for adequate model fit were defined based on current literature. To estimate the effect of each determinant, path coefficients were calculated.

3 FINDINGS

Costs of beneficial behavior and benefits of maladaptive behavior were restructured into social and practical costs due to high cross-loadings. The two items of behavioral control did not correlate and were thus used as separate constructs. Perceived practical costs such as the helmet being uncomfortable, impractical and hard to deal with when not wearing it had the largest effect in determining intention, followed by overarching attitudes, the expectation of others, and risk assessment when riding a bicycle. Self-efficacy, social costs, and beliefs about the effect of helmets had no effect. PMT and TPB scored well on the model goodness-of-fit criteria and applicability, while HAPA does not provide a satisfactory explanation. All in all, PMT as well as TPB achieved an explained variance exceeding .50. In terms of behavior, the intention is the best predictor and can only marginally be complemented by helmet-related behavior planning, while self-efficacy or behavioral control offer no additional explanatory value.

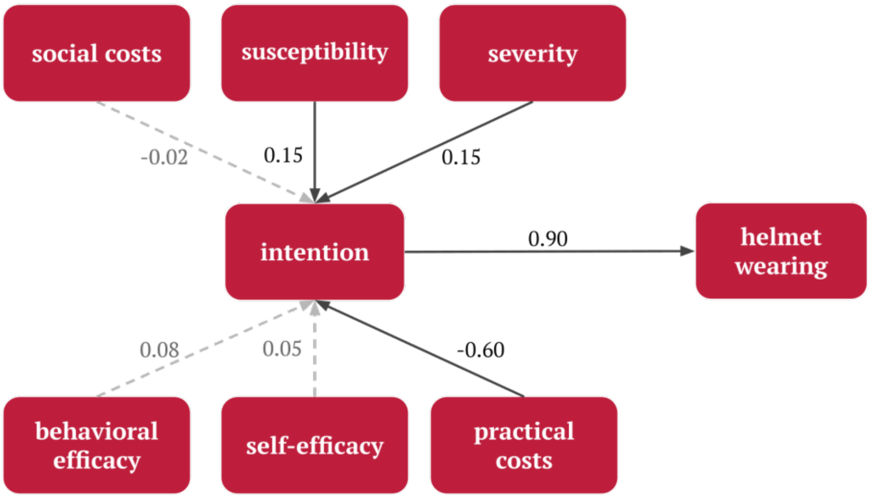

Figure 1: PMT with path coefficients.

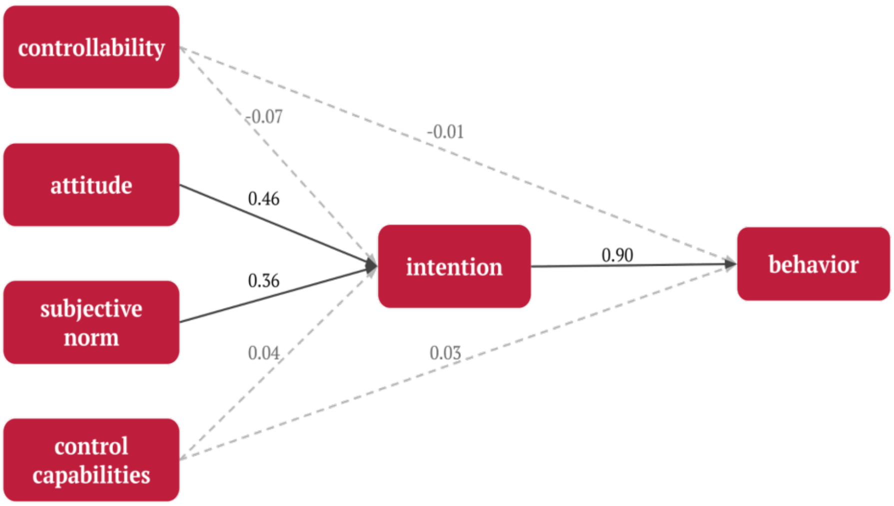

Figure 2: TPB with path coefficients.

Generally, the reported gap between intention and behavior can be considered small, about half of the respondents did not report a gap at all. Conditions, where special attention is paid to wearing a helmet, include long rides, slippery routes with much traffic, rides with sporting intent, or trips with children riding along. Most participants do not wear a helmet if the route is very short. Helmet wearers are also generally more cautious than non-wearers and, e.g., less likely to drive a car without a seat belt or use hard drugs.

4 IMPLICATIONS

Because of the cross-sectional nature of the study, no causal implications can be proposed. Nonetheless, big differences between helmet-wearing and non-wearing cyclists were identified. Since social costs were not identified as having an impact on helmet wearing, preventative campaigns focusing on the looks of helmets should not be funded. Instead, practical costs should be addressed by making it easier to wear a bicycle helmet and store it at a destination, for example by installing lockers for helmets close to bicycle parking stations, or making it possible to lock the helmet with an existing bike lock. Influencer campaigns on social media can promote further bicycle helmet life hacks. While it is not clear that reducing costs will make people get a helmet, it is clear however that helmet wearers do so because they perceive fewer costs.

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An experiment on the lateral steering behaviour of cyclists on narrow bidirectional cycle tracks

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Keywords: cycling, cycling safety, road design, cycle track width.

1 INTRODUCTION

Cycling contributes to public health because it requires physical effort [1] and offers economic and environmental advantages over motorized transport [2]. However, 41,000 cyclists die every year in traffic crashes, 3% of the total worldwide [3]. Most fatal bicycle crashes are collisions with motor vehicles. Severe injuries among cyclists, however, are mostly due to single bicycle crashes and their numbers are increasing [4, 5]. An international review showed that the share of hospitalised casualties due to single-bicycle crashes varied from 3% to 41% of the total number of hospitalised casualties [6].

Cycle tracks encourage cycling and sufficient pavement width is important to prevent single-bicycle crashes and collisions between cyclists [7-10]. Requirements on the minimum width of a bidirectional cycle track in guidelines are generally based on a 75 cm standard cyclist width including cyclists' lateral deviation from a straight line of some 20 cm combined with buffer zones [11, 12] as depicted in Figure 1. Requirements include a buffer zone between cyclists for passing and overtaking and a buffer zone between the cyclist and verge (buffer 1 and 2 in Figure 1). For instance for bidirectional cycle tracks where mopeds are not allowed and with well-designed verges such as in in Figure 1, the current Dutch Design manual for bicycle traffic [13, 14] recommends a minimum width of 1.5 m: three 25 cm buffer zones plus two times half of the width of a 75 cm wide standard cyclist. The assumed buffer zones in guidelines imply that cyclists choose a specific lateral position relative to the verge and other cyclists but few studies have tested these assumptions. In the past 10 years, lateral position was studied in a number of Dutch observational studies, mostly reported in grey literature and not specifically focused on the relationship between pavement width and lateral position [15, 16].

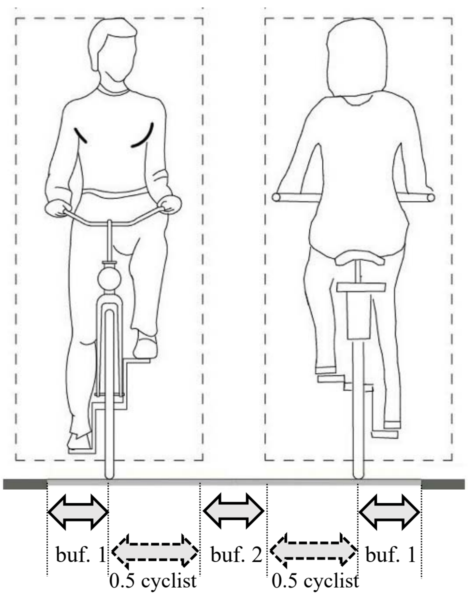

Figure 1. Lateral space required for cycling.

The aim of the present study is to investigate the relationship between cycle track width and lateral position. We conducted an experiment in which the cycle track width was manipulated to determine its effect on lateral position. The results have been compared with previous findings from literature.

2 DATA AND EQUIPMENT

A group of 24 experienced cyclists between 19 and 27 years participated in the experiment. The group consisted of 11 male and 13 female students from Delft University of Technology (TU Delft). The experiment took place on 8 and 9 December 2020 along a 3 m wide and 120 m long solitary bicycle track at the TU Delft campus. It was chosen because the negligible difference in height between the pavement and the verge would allow cyclists to swerve safely over the verge if needed. To change the width, bicycle tracks were marked using movable white band on the cyclists' left hand side while keeping the real verge at the right hand side. Widths of 1 m, 1.5 m and 2 m were applied. On the 1.5 and 2 m wide track an oncoming cyclist was simulated using a parked bicycle. The middle of the parked bicycle was located 44 cm away from the path's edge as Janssen [16] found this lateral position as average while riding abreast in an observational study. The width of 1 m is less than guidelines prescribe and was therefore considered too risky to include an oncoming cyclist.

After a training trial to get used to the instrumented bicycle, participants rode each of the five conditions (1 m, 1.5 m with and without parked bicycle, and 2 m with and without parked bicycle) three times. The order of the conditions was changed for each participant to avoid bias due to order effects. They cycled on an instrumented bicycle that measured speed by a GPS, lateral position by a LIDAR, and steering angle by a sensor on the steering wheel. A temporary 80 m long and 30 cm high barrier was placed on a fixed 1 m distance from the cycle track to allow the LIDAR to measure the distance between the rear wheel and barrier, i.e. lateral position. One-way repeated analyses of variance (ANOVA) were used to compare steering behavior between conditions.

3 RESULTS

The most important variable of this experiment is cyclists' lateral position. Higher values for lateral position are associated with a greater distance from the verge. Figure 2 depicts lateral position in each of the five conditions. Figure 2 also shows the position of the parked bicycle at the 1.5 and 2 m wide cycle tracks. As both the instrumented and parked bicycle were commonly used classic bicycles, the parked bicycle in Figure 2 has the average width of a Dutch bicycle [17].

A one-way repeated measures ANOVA was performed to compare median lateral position at the 1 m, 1.5 m and 2 m wide track without oncoming cyclist. A larger cycle track width significantly increases lateral position ($F(2,130) = 65.3$, $p < 0.001$), an increase of 19 cm if we compare the 2 m wide track with the 1 m wide track. Pairwise comparison with Bonferroni correction shows that lateral position significantly differs between all three conditions.

Two one-way repeated measures ANOVA's were performed to compare median lateral position while cycling on a 1.5 m and 2 m wide track with and without oncoming cyclist. The results show that passing causes cyclists to ride significantly closer to the verge. Median lateral position while passing on a 1.5 m wide track is reduced by 13 cm ($F(1,67) = 111.8$, $p < 0.001$). With a reduction of 9 cm, the decrease is somewhat smaller at a 2 m wide path ($F(1,68) = 46.1$, $p < 0.001$). Minimum lateral distance is relevant for crashes where the cyclist rides off the track. With 15 cm distance from the verge, lateral distance was lowest at a 1.5 m wide path while passing.

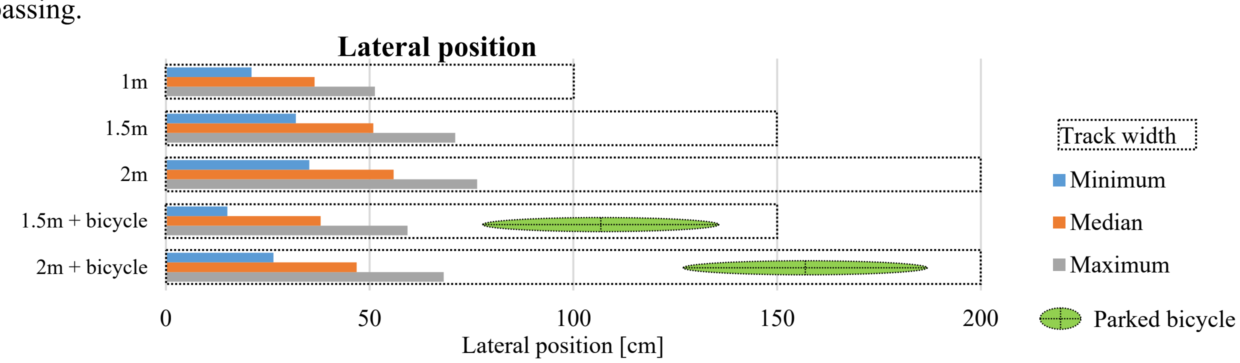

Figure 2. Lateral position of cyclists at cycle tracks with a width of 1 m, 1.5 m and 2 m.

Cycle track width significantly increases cycling speed from 14.6 to 15.5 km/h between the 1 m wide and 2 m wide track ($F(2,66) = 4.5$, $p = 0.015$) but the absolute difference is small.

4 DISCUSSION AND CONCLUSIONS

This study shows that an increase of cycle track width causes cyclists to ride further away from the verge and keep more distance from oncoming cyclists. The finding that cyclists approach the verge closer at narrower tracks is important as cyclists ride off the track in approximately a quarter of all single-bicycle crashes. Moreover, recent crash studies have shown that reduced pavement width is associated with a higher risk of bicycle crashes. Considering how close cyclists approach the verge and an oncoming cyclist on a 1.5 m wide cycle track, it seems that less width would substantially increase risk, even under favourable conditions. additional results and a more detailed discussion will be added in the full paper.

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Increased bicycle helmet use: Time series observational studies on bicycle helmet use in Denmark from 2004 to 2021

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Keywords: time series observational study, helmet use, cyclist behaviour, behavioral change, road safety campaigns.

1 INTRODUCTION

Using a bicycle helmet markedly reduces the risk of head injuries. The most recent systematic review and meta-analysis has documented that the use of bicycle helmet reduces the risk of serious head injuries by 60 % [1]. Given the large safety-gains from wearing a helmet while cycling, it is highly relevant to promote the uptake of bicycle helmets while also measuring how the prevalence of bicycle helmet use evolves over time across different groups. In Denmark, bicycle helmet use has been promoted in several nationwide campaigns targeting both the general cyclist population and cycling school children. Since 2004, the use of bicycle helmets among cyclist in Denmark has also been measured observationally in two different nationwide time series. One time series (termed "city traffic") consists of observations of cyclist across all age groups in city traffic. The other nationwide time series (named "school traffic") consists of observations in front of schools, and only includes observations of cycling children. This paper presents the results of these two observational time series, while also cautiously linking the increase in bicycle helmet use to campaigns that have promoted the uptake of bicycle helmets.

This paper is structured as follows. First, the methods of the observational bicycle helmet studies are presented. Second, the results of the bicycle helmet observational time series are presented. Third, the discussion section assesses potential explanations for the increased bicycle helmet use in Denmark.

The paper concludes that the use of bicycle helmets has increased markedly in Denmark. In 2004, approximately 6 % of the observed cyclists in city traffic used bicycle helmets. This number increased to 28 % in 2014 and to 48 % in 2021. In school traffic, helmet use among cycling school children increased from 33 % in 2004 to 60 % in 2014 and to 80 % in 2021.

2 METHODS

Since 2004, The Danish Road Safety Council has conducted nationwide systematic bicycle helmet registrations among cyclists in Denmark. The observations are conducted in different parts of the country, and most observations are carried out by municipalities. From 2004 to 2010, the observations were carried out every second year and since 2010, bicycle helmets have been registered every year. The studies are carried out at roughly the same locations in different cities. The method of observation has been substantially unchanged since the first study in 2004. Throughout the years, the data collection period has been from the middle of August to the beginning of September.

The nationwide observations consist of two separate time series: "city traffic" and "school traffic". The first time series ("city traffic") consists of observations of cyclists across all age groups in city traffic. In this time series, cyclists are observed on weekdays during the morning, midday, and afternoon. In the second time series ("school traffic"), only cycling school children (aged 6-16) are observed, and these observations are carried out in front of schools in the morning. In 2020, a total of 11,731 cyclists were observed in city traffic while

8,315 cycling school children were observed in school traffic, A more detailed description of the methods can be found in the latest bicycle helmet report (in Danish) [2].

3 RESULTS

3.1 The use of bicycle helmets in city traffic

Since 2004, the use of bicycle helmets among cyclists in Denmark has increased significantly. In the "city traffic" time series where cyclists across all age groups are registered, helmet use has increased from 6 % in 2004 to 48 % in 2021. In the "school traffic" time series where only cycling school children are registered, helmet use has increased from 33 % in 2004 to 80 % in 2021. Figure 1 shows the prevalence over time, while also highlights how the increase of bicycle helmet use in Denmark has occurred in two waves. The first wave of increasing helmet use occurred from 2004 to 2010. During this period, helmet use rose from 33 % to 56 % among cycling school children, equivalent to an average annual rise in helmet use of almost 4 percentage points. Among the general cyclist group in city traffic, helmet use rose from 6 % in 2004 to 25 % in 2010, corresponding to an average annual increase of just above 3 percentage points. In the ensuing years from 2010 to 2014, the use of bicycle helmet almost stagnated and only increased marginally from 56 % to 60 % in school traffic and from 25 % to 28 % in city traffic. Since 2014, the prevalence of bicycle helmets started growing again. In school traffic, helmet use among school children rose from 60 % in 2014 to 82 % in 2020 before declining slightly (albeit statistically significantly) to 80 % in 2021. From 2014 to 2021, the total increase in bicycle helmet use among school children is equivalent to an average annual rise in helmet use of almost 3 percentage point. In city traffic, helmet use did not increase from 2014 to 2015, but from 2015 and onwards, helmet use increased from 28 % to 48 % in 2021.

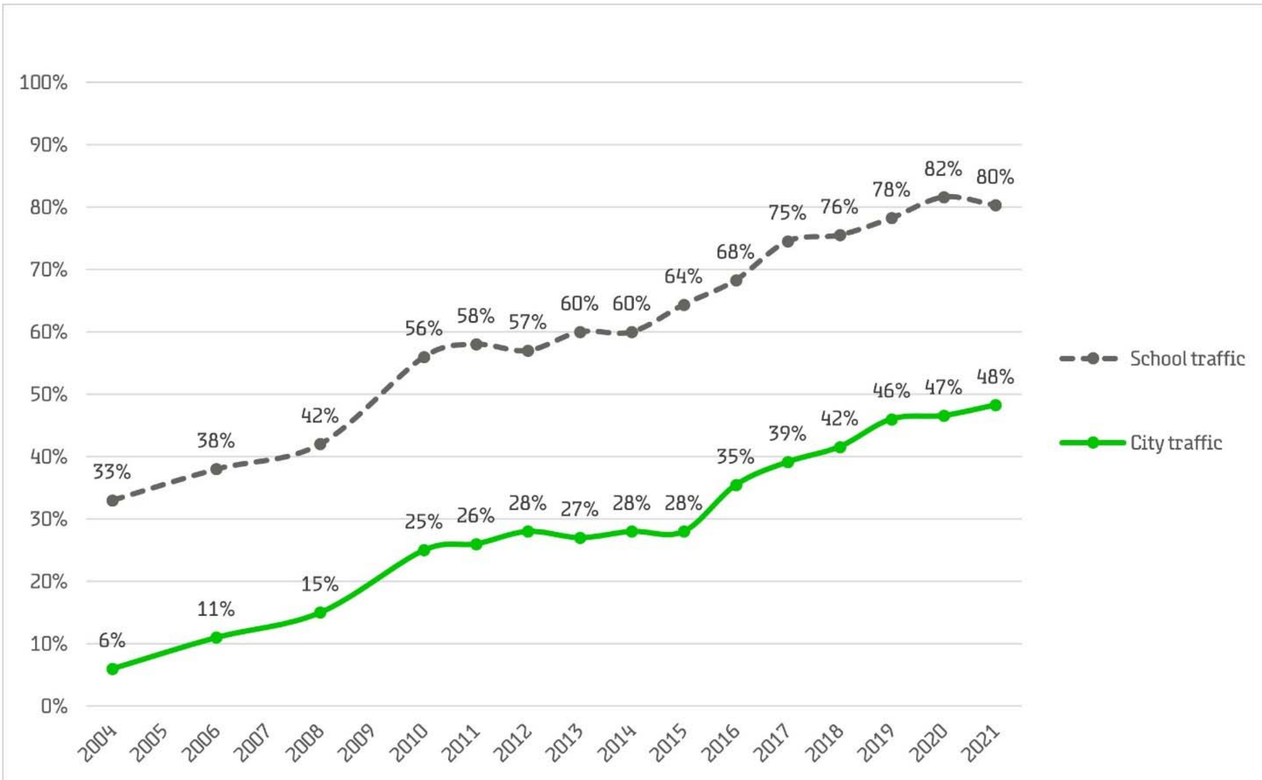

Figure 1: The use of helmets among cyclist in Denmark, 2004-2021.

4 DISCUSSION

What are the causes of the uptake of bicycle helmet use in Denmark? How did bicycle helmet use evolve from being a rare sight to becoming a security device that almost half of all cyclists in city traffic and 8 out of 10 cycling school children use? Several potential explanations exist.

One potential explanation is the campaign activities in Denmark that has promoted the use of bicycle helmets. The two waves of increased bicycle helmet use in 2004-2010 and from 2014 onwards coincided with nationwide campaigns that promoted bicycle helmets. In contrast, the period from 2010 to 2014 where bicycle helmet use stagnated, was marked by an absence of nationwide bicycle helmet campaigns. Starting in the autumn of 2014, a new nationwide campaign was launched. The campaign focused on the parents of preteen school children and praised parents for insisting that their children use bicycle helmets. The campaign consisted of several humorous music videos that went viral on YouTube[1]. An evaluation of the first campaign video in 2014 showed that 46 % of target group (parents with children aged 8 to 12 years old) had been speaking with their children about the campaign [3].[2]

While the campaigns promoting helmet use might explain some of the increased helmet use among cyclists in Denmark, it most likely cannot explain all of the increased bicycle helmet use. One other potential explanation for the uptake of helmets is self-enhancing processes. As using a helmet becomes more common, cyclist do not stand out by wearing a helmet. This is turn partly removes one of the barriers for cyclists to use a helmet. Furthermore, as wearing bicycle helmets becomes the norm among school children, it might be perceived as socially unacceptable not to ensure that a child wears a helmet. Since 2017 more than 9 out of 10 cycling school children aged 6 to 9 have been observed wearing a helmet while cycling to school [2].

Finally, the increased bicycle helmet use might also be linked to secular processes in which the population in general display more safety-oriented behaviours in road traffic.

5 CONCLUSIONS

In Denmark, the use of bicycle helmets has changed from being a relatively rare sight to being widespread. In 2004, 6 % of the observed cyclists in city traffic used bicycle helmets. This number increased to 28 % in 2014 and 48 % in 2021. In school traffic, helmet use has increased among school children from 33 % in 2004 to 60 % in 2014 and 80 % in 2021. The potential explanations for the increased helmet use are many and range from bicycle helmet campaigns, self-enhancing processes, changing norms, to broader secular trends.

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[1] As of 2022, the first campaign video from 2014 had more than 6 milion views, and the third campaign video from 2017 had more than 12 million views. In comparison, the population in Denmark is less than 6 million.
[2] Using the logic of the interrupted time series design, one can conceptualize the launch of the new campaign as an exogenous shock and thereby cautiously estimate the effect of the campaign on bicycle helmet use in school traffic. If the pre-campaign upward trend in bicycle helmet use in school traffic from 2010 to 2014 (average annual increases of 1 percentage point) had continued into the period of 2015 to 2021, one would have expected helmet use to be at 67 % in school traffic instead of 80 %.

Where do bicyclists interact with other road users? Delineating potential risk zones in HD-maps.

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Keywords: risk zone, vulnerable road user, connected and autonomous vehicle, high definition map.

1 INTRODUCTION

International crash statistics indicate a decrease of bicycle crashes, but at a slower pace compared to total crash numbers. The share of crashes with involved cyclists is above the modal share (see [1] for an overview). Depending on sources, types of analyses, and geographic regions, crash statistics suggest high rates of single-bike crashes and crashes between cyclists and other vulnerable road users (VRUs) [2], while cars are opponents in more than half of all fatal crashes in the European Union [3]. The design of the road environment is of particular relevance for crash risks. A study from London found three times higher injury odds for cyclists at intersections [4]. Connected and automated vehicles (CAV) are frequently said to increase the safety level in road traffic since they are less prone to human errors [5]. This might hold true in transport systems with little complexity, such as highways [6]. However, when it comes to complex situations in multimodal systems with multiple interactions between different road users, such as intersections in urban environments, existing solutions are not sufficient yet in terms of protecting VRUs.

We identified two fundamental flaws in the (over-) simplistic conclusion of increasing traffic safety by increasing the amount of CAVs at the current level of system maturity and reliability. First, to operate correctly, CAVs rely on technology-based communication protocols such as vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication. This requires every entity in traffic (X) to be connected and reporting its current position as well as intended route. However, VRUs are not yet connected to such systems due to technical and ethical reasons. Therefore, they cannot be adequately embedded in V2X systems. Second, CAVs use a wide range of active and passive sensors, which form a technological base to detect and estimate the location, movement and intention of road users. However, sensors and the computational units fed with the sensed information are not bulletproof to malefaction or a cyber-attack leading to the risk of misinterpreted information. In addition, the amount of data that needs to be processed is paramount. Intelligent spatial filters could cut down this amount dramatically and thus reduce the probability of errors.

In order to contribute to the safety of VRUs in the interplay with CAVs in current systems, we propose a geo-spatial model, which delineates potential interaction risk zones from high definition (HD) maps and enriching these zones with additional information. These enriched risk zones are then provided as standardized OGC web service, which can be integrated in V2X systems. With this, we contribute to the visibility, and thus the safety of VRUs in connected transport systems. From a methodological point of view, the proposed model is a first step in integrating spatial context and semantic information explicitly into V2X communication.

2 PROPOSED WORKFLOW

Within the nationally funded research project Bike2CAV, which revolves around safety of VRUs, particularly bicyclists, in connected transport systems, we developed a geo-spatial model and analysis workflow for identifying and enriching interaction zones.

In order to navigate autonomously on roads, CAVs rely on high precision GNSS to locate themselves on high definition maps (HD-map). A HD-map is a highly accurate, three-dimensional data model, which describes the road space at the level of lanes. Each lane in the real world is represented by two enclosing borderlines. This results in two-dimensional, geo-referenced entities, describing the shape (geometry) of the respective lane and additional attributes, such as access rights or direction of flow [7]. Our approach is to translate these HD-maps into features in a geographical information system (GIS), where they can then be overlayed, further analyzed and enriched with additional data. The workflow consists of the following steps:

1) integrate and translate the HD-map into a GIS environment
2) identify interaction zones between lanes based on access and turning information using spatial analysis
3) map national crash statistics onto the identified interaction zones
4) provide access to the enriched interaction zones via OGC services published to the internet

The resulting interaction zones are areas in the road spaces where two or more lanes spatially overlap. In these zones, different road users might interact. The probability for potentially risky interactions is then deduced from national crash reports. We used the relative distribution of crash patterns and translated them into clustered scenarios, such as right turning car intersects with a bicyclists crossing in straight direction. The probability of the different types of interactions was then mapped on the interaction zones in the HD-map, considering access rights and turning relations.

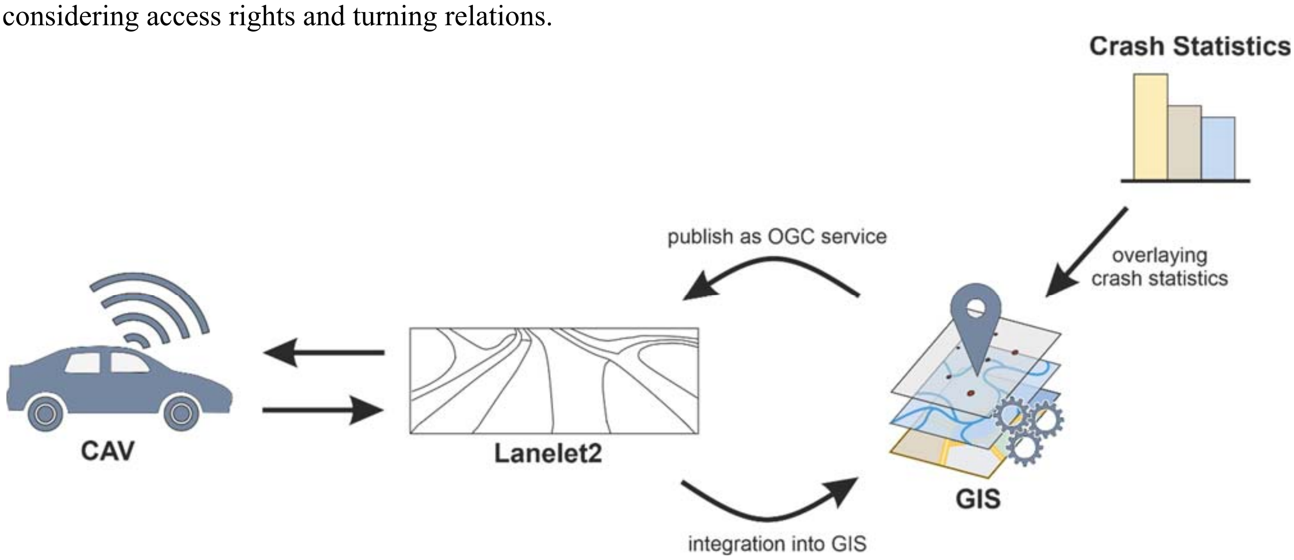

Figure 1: Proposed workflow to derive risk zones by mapping national crash statistic on interaction zones.

3 RESULTS

By applying the outlined workflow, a general probability for risky interactions can be mapped on the interaction zones. This makes the potential risk of specific turning relations within intersections spatially visible. CAVs can access and use this information in real time via OGC services published to the internet. The workflow has been implemented on two test intersections. One represents a four-legged, high volume intersection in the city of Salzburg (Austria) whereas the other covers a three-legged intersection in a rural area. Our approach identifies potentially dangerous interaction zones and indicates the statistically derived possibility of a collision. Making areas where dangerous interactions occur visible to CAVs prior to a recognition with onboard sensors, increases the perception of VRUs within the domain of connected transport systems. Thus, the risk for a crash can be reduced. Moreover, the enriched interaction zones serve as cost efficient and intelligent spatial filters for onboard sensors of CAVs. Another potential application of the identified interaction zones is to adapt the physical condition of intersections. Knowing about dangerous interactions within intersections, gives planners and decision makers the opportunity to adapt the layout of intersections, or optimize the phases of traffic lights in order to mitigate the crash probability.
In a next step of the Bike2CAV research project, the derived interaction zones will be evaluated using real world trajectories from VRUs on the demo intersections. This allows comparing the derived crash statistics with the actual behavior of cyclists and pedestrians in order to assess the correctness of the workflow.

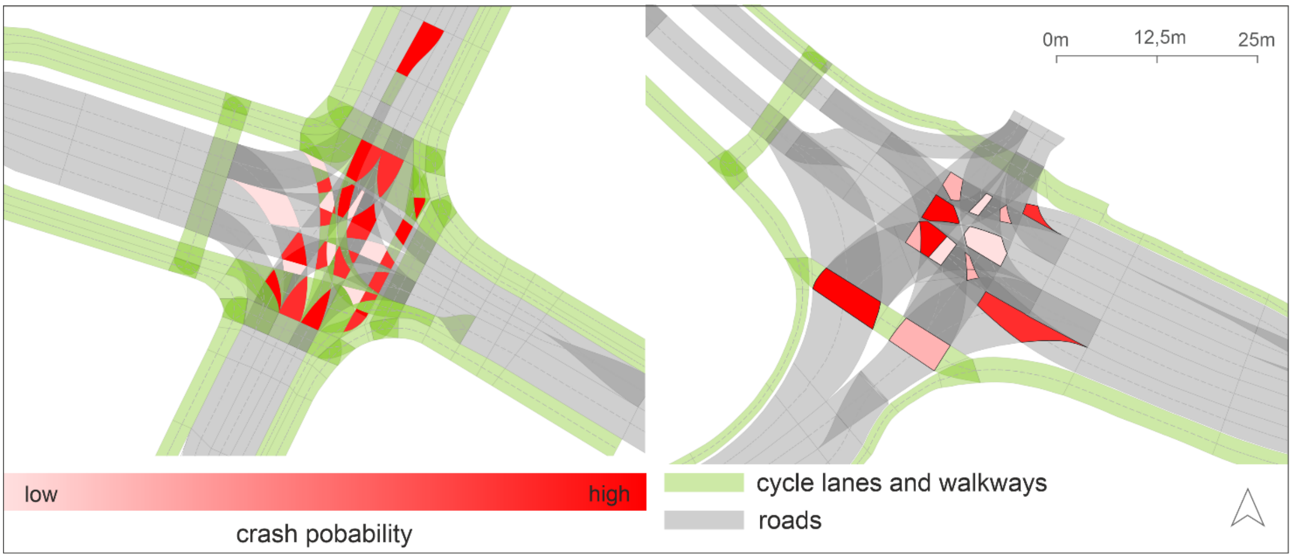

Figure 2: Enriched HD-map displaying the crash probability for the interaction zones within the two test intersections.

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Video-based assessment of cyclist-tram track interactions in wet road conditions

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Keywords: single cyclist falls, surrogate safety measures, tram tracks, video analysis.

1 INTRODUCTION

Cyclist underreporting of lower severity and single cyclist collisions to police results in the underestimation of the societal costs of lower severity and single cyclist collisions [1], [2]. Prevention strategies for these types of collisions are becoming a popular area of research, and video-based approaches have obvious potential for these cases, allowing for detailed analyses of underreported lower severity and single cyclist falls. Video-based studies have been used to investigate site-specific cyclist safety issues such as railway crossings [3]. They have also been used for near-collision or near-miss incidents and Surrogate Measures of Safety (SMoS), e.g., [4]. A recent Irish study has identified the most common collision configurations and factors with the inclusion of unreported cases [5]. Findings indicate that falls involving interactions with light rail tram tracks are common in Dublin; they were the most common infrastructural collision partner in this study and a contributing factor in 23% of single cyclist collisions (ibid.), supplementing international findings [6], [7]. Furthermore, along with increasing popularity of cycling, many new light rail systems are being implemented across Europe as part of a broader move towards sustainable transport [8]. Accordingly, further investigation is required to avoid potential conflicts. Therefore, this study aims to use video-based assessment to correlate fall risk with trajectories and crossing angles.

2 METHODS

2.1 Data collection

Traffic camera footage was collected in October/November 2021 following institutional ethical approval. This involved manual screening, annotation and extraction of cyclist interactions with tram tracks from 9 traffic cameras in Dublin City Centre. We focused on weekdays, daylight conditions and peak commuting hours [1]. Wet road conditions are a significant factor for cyclist falls on tracks (21% of cases) [5]. We initially assessed a sample that included both dry and wet conditions but a significant preliminary analysis found no falls during dry conditions. Therefore, we focused on periods with wet road conditions.

2.2 Frequency and risk analysis

Using the footage, exposure and time-based risk analyses were performed to assess the rate of unsuccessful crossings (falls and near-falls involving evidence of loss of control) at each recording site.

2.3 Crossing angles and trajectories

Footage of unsuccessful crossings, and a random sample of the successful crossing cases were extracted for analysis. T-Analyst software (developed in the European InDev project) was used to calculate cyclist velocities and trajectories [9]. T-calibration allows for ground-plane calibration of monocular traffic camera footage from manually annotated scene points in both the traffic camera footage and a scaled satellite image of the recording location (e.g. Google Earth) [10] (see Figure 1). An independent-samples t-test was used to compare mean crossing angles between successful/unsuccessful crossings ($\alpha = 0.05$).

3 RESULTS

Table 1 is a summary of the collected data. A total of 2905 cyclist interactions with tram tracks were surveyed over two periods with wet road conditions. Extracted footage includes all 13 unsuccessful crossings (UC - 9 near fall cases, and 4 fall cases), and a random sample of 2,891 successful crossings (SC) for a case-control analysis. A total of 9 unsuccessful crossings were identified over Period 1 out of 2741 cyclists, corresponding to an UC rate of $3.3x10^{-3}$, or 3 in 1000. A disproportionally high rate was observed in camera 6 (Westmoreland St./College St.) (4 UCs for 213 cyclists), therefore, a further 5 hours of footage was examined in this location (Period 2). Overall, this location has a UC rate of $2.1x10^{-2}$, or 21 in 1000.

Table 1: Summary description of the study data.

Camera	No. cyclists	Hours	UC	SC sample	UC/No. cyclists	UC/Hour
1	198	7	1	10	0.0051	0.1429
2	145	7	0	7	0	0
3	181	7	1	9	0.0051	0.1429
4	116	7	0	6	0	0
5	410	7	1	21	0.0024	0.1429
6	377	12	8	19	0.0212	0.6667
7	324	7	1	16	0.0031	0.1429
8	551	7	1	23	0.0018	0.1429
9	603	7	0	30	0	0
Total	**2,905**	**68**	**13**	**141**	**0.0045**	**0.1912**

As a preliminary analysis, trajectories of 5 unsuccessful crossings and a random sample of 7 successful crossings of the inside track were annotated for camera 6 (Figure 2). Mean crossing angles were higher for successful crossings (x̄ = 17 degrees, SD = 3.70), compared to unsuccessful crossings (x̄ = 9 degrees, SD = 6.37), with statistical significance ($p = 0.017$). Average velocities were similar: 4.2m/s for successful crossings vs. 4.1m/s for unsuccessful crossings.

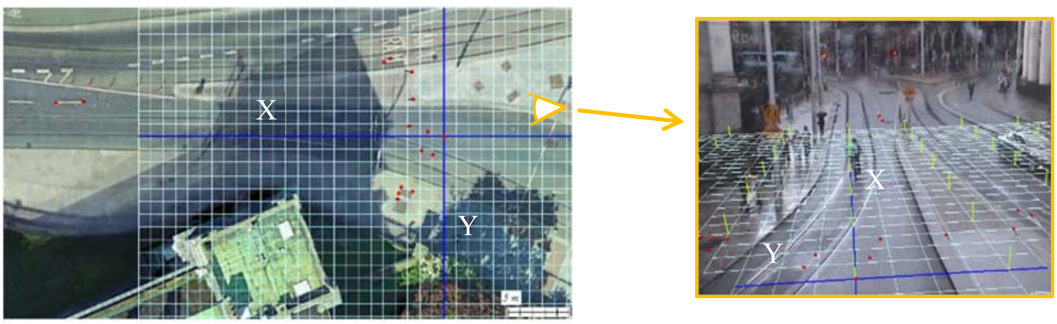

Figure 1: Ground plane calibration for Westmoreland St./College St. (camera 6).

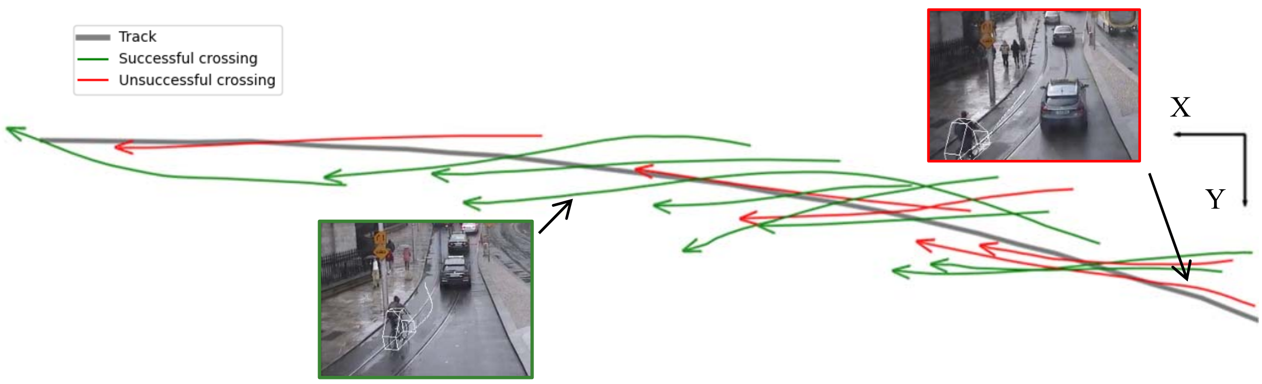

Figure 2: Trajectory analysis of cyclist interactions with the inside track at Westmoreland St./College St. (camera 6).

4 DISCUSSION & CONCLUSIONS

We present the first video-based trajectory and fall analysis for cyclist interactions with light rail tram-tracks. Our analysis focuses on wet road conditions as a common and safety critical edge case. Though rates are lower than a similar study in the US for railway tracks [3], cycling volumes in the study areas resulted in a high number of unsuccessful crossings. High overall incidence numbers for unsuccessful crossings over this short study period with limited coverage of the track network highlight the significance of the safety issue, particularly in Westmoreland St./College St (camera 6). Furthermore, an additional unsuccessful crossing was noted in a nearby camera (camera 5: Grafton St./College Green.). As expected, our further analysis of crossing trajectories for camera 6 indicates that crossing angle is a predictor of crossing success. Furthermore, falls on the inside kerb are common here, and all crossing angles are low for both successful and unsuccessful crossings (≤ 20 degrees - excluding one case with intentional mounting of the kerb). This is likely due to the proximity of the nearside kerb, which limits crossing angle. These findings indicate that crossing angle could be used as a SMoS (i.e., a safety-related indicator without the need for fall footage), allowing for rapid assessment of potential areas of conflict. Future work will include a complete trajectory analysis of the data at all study locations, to supplement these findings and determine site-specific safety issues.

ACKNOWLEDGEMENTS

The authors thank the Irish Road Safety Authority (RSA), which is funding this PhD research under the RSA Helena Winters Scholarship for Studies in Road Safety. The authors also thank Dublin City Council for data provision.

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Safe Cycling in Winter - Results of a use case on the role of snow and ice removal in the city of Hamburg, Germany

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Keywords: winter cycling, winter road maintenance, safety, gritting material.

1 INTRODUCTION

An increase in cycling mode share and cycling performance is an essential part of future transport development (Buehler and Pucher 2011; Schwanen 2015). In order to achieve the climate goals of the Federal Republic of Germany, the share of cycling must be significantly increased (BMVI 2021). An important part of this is to make cycling safe also in harsh weather conditions as seen in winter. While cycling mode shares have increased in the other seasons in recent years, a slump in cycling performance can be observed especially in winter (Nobis 2019). Studies to date have attributed this to weather conditions (temperature, precipitation) (Winters et al. 2011) and, above all, to the declining subjective feeling of safety among cyclists. Many German municipalities are therefore working on a winter service concept for cycling in order to make cycling safe even in winter conditions.

This raises the question of how winter services can be provided effectively and efficiently. Together with the city of Hamburg, Germany, we developed a research design to address this topic. In the study area of the city of Hamburg, grit is currently spread on cycle paths in winter. This method has been criticised by cyclists. Chippings or gravel hardly offer any safety when snow freezes over, as it sinks in. In addition, it must be removed again as soon as the snow or ice cover has thawed, as it has a negative impact on riding safety on dry cycle paths, especially when cornering and/or braking. This reduces the comfort of the cyclists and is often critizied by the cyclists.
A possible alternative is rock salt (NaCl) or its solutions. In Hamburg, however, its use on separated cycle paths is prohibited as rock salt has negative effects on the urban greenery and trees. In addition, rock salt has a corrosive effect on bicycles, especially the drive.

Therefore, an environmentally sound alternative for winter maintenance on segregated cycle paths that is acceptable to cyclists must be found. In many German cities but also globally, the challenge is to find a balanced solution between environmental protection and safe cycling. However, possible alternatives have to go through an approval process before they can be used.

To solve those questions, we conducted several surveys which are summarized in this paper. It consists of five sections: Section 2 highlights the wishes and demands on cycling(infrastructure) in winter from the cyclists' point of view. In section 3, the current state of winter maintenance in German cities is reviewed. Section 4 describes the selection and ecological footprint of alternative gritting materials, while section 5 describes the experiences of users in a field test.

2 METHOD

In this study, different qualitative and quantitative methods were applied. First, 3,.521cyclists were interviewed in an online survey about their everyday use of cycling in winter and the associated barriers. The main focus was on satisfaction with winter services and possible drivers for higher cycling performance in winter. In addition, more than 50 cycling officers in German cities were interviewed regarding the operational design of winter road maintenance.

In parallel, a selection of possible gritting materials was made. These were evaluated according to economic and ecological criteria. Subsequently, four gritting materials (sodium chloride, sodium formate, calcium magnesium acetate and potassium acetate) were tested in the field in non-public areas in the city of Hamburg. In addition to the test of the operational use by the Hamburg city cleaning service, cyclists were also surveyed with regard to safety of the gritting materials.

The presented result will be a synopsis of the applicability of alternative gritting materials on cycle paths. The main evaluation criteria have already been defined, but final studies on the environmental compatibility of the tested gritting materials are still pending and will be available by the time of the conference.

3 RESULTS

The online survey of cyclists showed a significant decrease in the frequency of cycling in bad weather conditions ("-5°C-0°C, precipitation as rain or snow) which is in line with former findings (Winters et al. 2011). The likelihood of cycling also decreased significantly for all-weather cyclists due to snow or icy roads (see Fig. 1). 26% of winter cyclists would cycle significantly more often if winter services were of a higher quality. Improved or good winter road maintenance could also increase subjective safety, the higher the subjective safety, the more often cycle people during winter. Complete mechanical clearing is desired, followed by gritting and thawing agents.

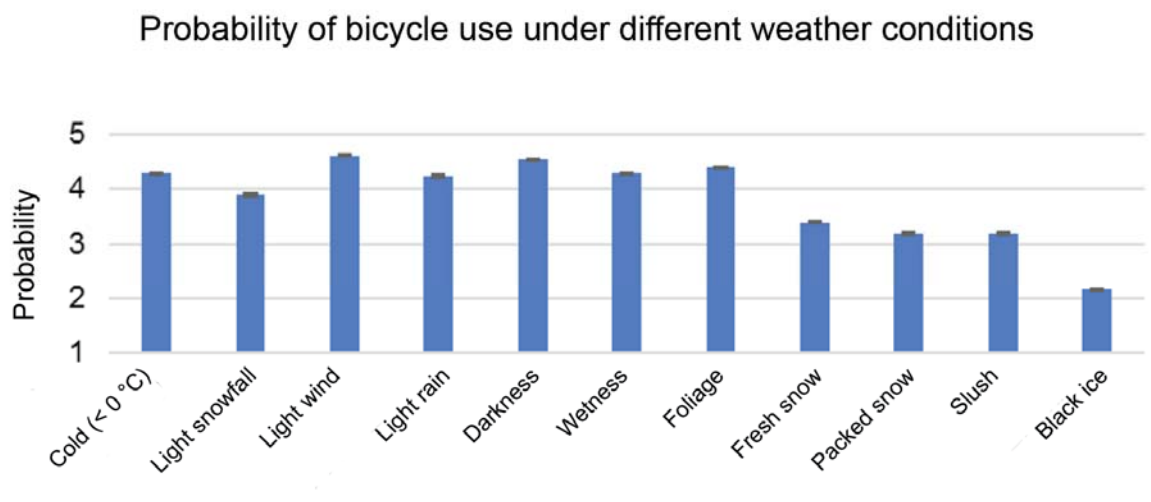
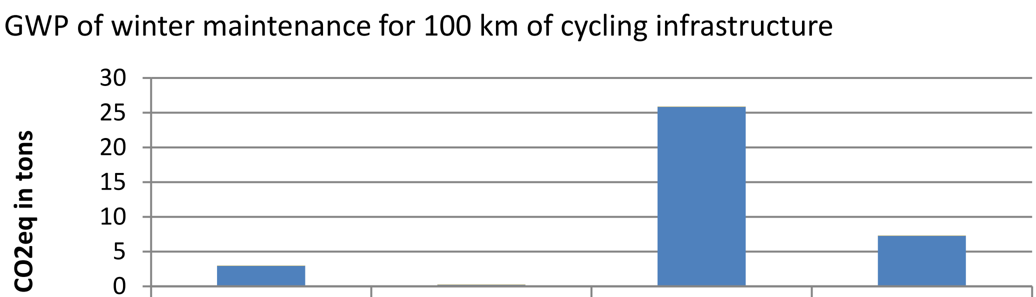


Figure 1: Probability of bicycle use under different weather conditions, (5 = high, 1 = not cycling, N = 3,521)

The survey of >50 cycling officers in Germany showed that gravel and sodium chloride are mainly used in municipal practice. Furthermore, the municipal officers are generally rather satisfied with the winter service provided. However, this does not necessarily reflect the perception of cyclists. The ban on NaCl in some municipalities and the relatively high effort required for cleaning after the use of gravel justifies the further search for alternatives for winter maintenance on cycling facilities.

However, possible alternatives must be justifiable ecologically and economically, as well as operational criteria. Following a market analysis, four gritting materials were shortlisted and subjected to laboratory tests. An analysis of the ecological effectiveness suggests the use of sodium formate as an alternative to NaCl. Besides potassium carbonate, this is the only gritting material that is competitive with sodium chloride in terms of environmental impact. This can be seen as an example in Fig. 2. In addition to the greenhouse effects, the acidification potential, ozone formation potential, energy input and eutrophication potential were also examined. Besides a laboratory study on the thawing effectiveness was conducted. It showed the best results for NaCl followed by Sodium formate.



	Sodium format	Sodium chloride	CMA	Potassium acetate
Cleaning in t	0,002	0,002	0,002	0,002
Operation (LDV Euro 6) in t	0,022	0,020	0,020	0,020
Operation pre-chain in t	0,003	0,003	0,003	0,003
Manufactoring in t	2,9	0,2	25,8	7,3

gritting material

Figure 2: GWP of winter maintenance on cycling infrastructure

In practical tests by 54 cyclists at two sites in Hamburg, sodium formate also proved to be an alternative to NaCl, which is banned in some cities, which can be seen in figure 3. Therefor the four gritting materials were applied to defined sections of cycling infrastructure. Passing cyclists were asked to test the different sections in terms of visibility and safety of the used gritting material in semi-structured interviews.

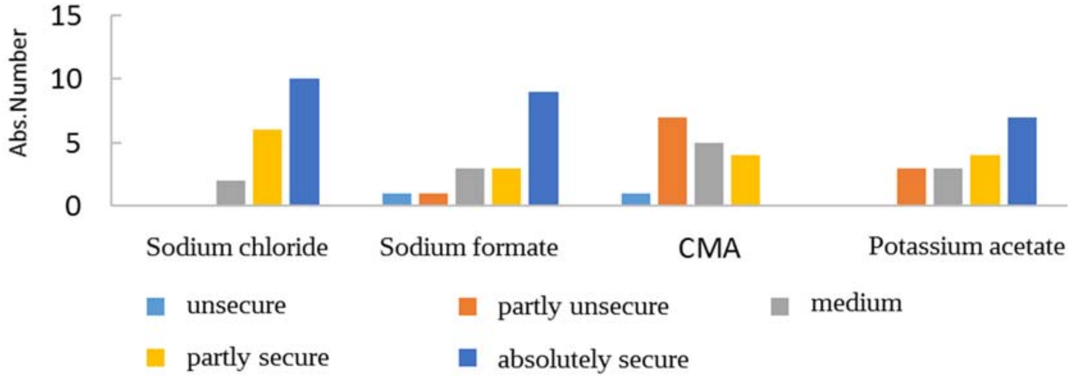


Figure 3: cyclists' evaluation of safety for different gritting materials (N=54)

4 CONCLUSIONS

Effective de-icing is crucial for the promotion of winter cycling, as many cyclists name the reduced safety because of ice and snow as their biggest barrier to cycle all year round. German cities are using grit and sodium chloride until now, which have both shortcomings in terms of cyclists' safety or a negative impact on nature. Sodium formate proved as a possible alternative up to now. If further laboratory tests concerning soil and waters are positive, it should be considered as a new medium for winter maintenance for cycling infrastructure.

Secondary task engagement, risk-taking, and safety-related equipment use in German bicycle and e-scooter riders - an observation

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Highlights

- Out of 4,514 observed riders, 12.3% engaged in one or more secondary tasks
- Mobile phone use was low (1.3%), banned use was found in negligible numbers (0.8%)
- Additional safety equipment was more prevalent for bicyclists than e-scooter riders
- Secondary tasks were associated with rule violations and at-fault conflicts
- Five rider profiles were extracted by cluster analysis

Keywords: E-Scooters, Bicycles, E-bikes, Shared mobility, Secondary task, Safety equipment, Observational study, Infrastructure use, Riders' characteristics

1 INTRODUCTION

It has been shown that engagement in secondary tasks may contribute to cyclists crash risk [1], meditated by cycling errors or risky behaviors. For influences on secondary task engagement, it is generally found that phone use is negatively correlated with age. In most studies, males are more found engaged in phone tasks than females. It was also found that users of a bicycle-sharing program more often to wear headphones and engage in more unsafe behavior. The use of safety gear (e.g., wearing a helmet, using reflectors) is often negatively correlated with distracted cycling. Also, cyclists engaged in a secondary task exhibit other risky behaviors more often [2].

The present study's first aim was to get (an updated) estimate of the observable frequency of different secondary tasks, use of additional safety equipment, and rule violations while riding bicycles and e-scooters in Germany. The second aim was to examine possible differences in secondary task engagement, use of additional safety equipment, and rule violations between different types of users of the cycling infrastructure, i.e., riders of conventional bikes, e-bikes, scooters, and e-scooters. A third aim was to explore whether riders' secondary task engagement is related to active safety precautions (e.g., wearing a helmet), traffic rule violations, and at-fault conflicts and if there are rider profiles regarding safety-related behaviors. As the study is explorative, no hypotheses were formulated.

2 METHODS

In a cross-sectional design, observations were made between November 12, 2021, and November 19, 2021, at five locations with differing infrastructures on public urban roads within Braunschweig, Germany. Overall, 4,514 bicycle and e-scooter riders were observed concerning their used vehicles type, secondary task engagement, use of additional safety equipment, and traffic rule violations. Two types of predictors were used. The first set of predictors (location and cycling facility, time of day and day of the week) was quasi-experimental, as their instances had been actively selected. The second set of predictors (weather and lighting conditions; bicycle or scooter riders' gender and age; vehicle types and working as a delivery worker) could not be actively selected and recorded as found.

3 RESULTS

Overall, 13.4% of all riders were engaged in any secondary task, wearing headphones or earphones being the most frequent behavior (6.7%), followed by conversations with other cyclists (3.7%). Banned mobile phone use was low (0.8%). A helmet was worn by 17.8% of riders, reflective or fluorescent clothing by 6.6%, and 0.2% of had a pennant or spacers mounted on their bike. Nine in ten riders observed in this study (90.8%) did not commit any traffic rule violation.

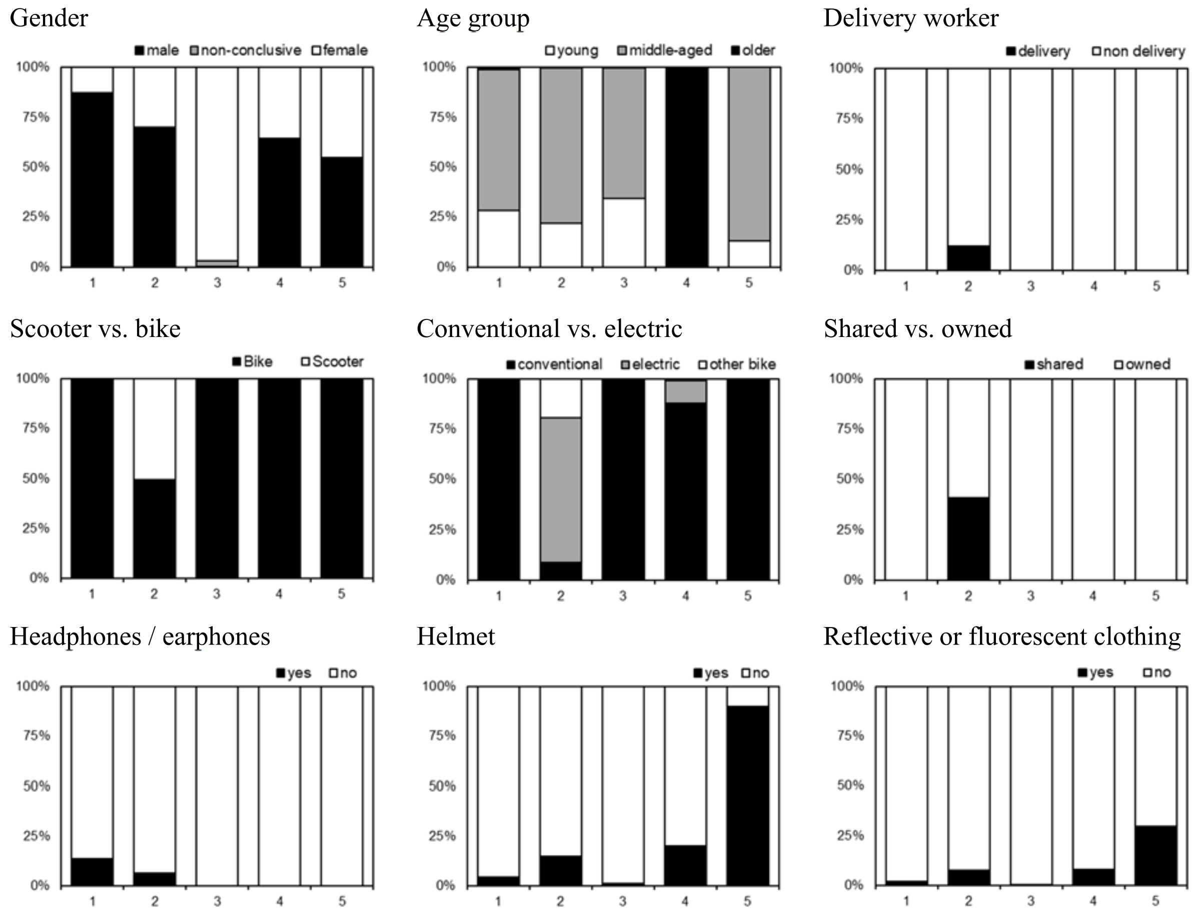

Figure 1: Five clusters of riders and their related profiles, vehicles, behaviors, and equipment (selection).

Location, weekend vs. weekday, gender, age, and being a delivery worker were significant predictors for secondary task engagement. For the use of any additional safety equipment, location, weekend vs. weekday, time of day, gender, age, using a scooter or a bike, conventional or electric, and being a delivery worker were significant predictors. Rule violations were predicted by location, weather, lighting conditions, weekend vs. weekday, time of day, gender, and age.

Secondary task engagement was positively correlated with traffic rule violations and at-fault conflicts and negatively with the use of additional safety equipment. Cluster analysis on vehicle types and behaviors revealed five groups of riders. The first cluster comprised about a little less than half of all observed riders. In this cluster, the vast majority of riders are male, middle-aged, and young. With only one exception, all riders used bicycles, all vehicles are owned. Riders in this cluster are the most likely to use their phone, wear head- or earphones, or converse with others. Riders in this cluster are second to last likely to wear helmets or reflective or fluorescent clothing. They are also the most likely to commit traffic rule violations and were also most often found in at-fault conflicts with others.

Cluster 2 is characterized by vehicle type: here, all e-scooter riders and most riders of electric vehicles (are grouped. Also, in this cluster are all riders of special bikes (e.g., cargo All seventy delivery workers and all users of rented vehicles are found in this cluster. Most of the riders performing secondary tasks not clustered in Cluster 1 are found in this cluster. Safety equipment is moderately often seen within this group: Riders in cluster 2 often commit rule violations and were the second most likely to be in at-fault conflicts.
Cluster 3 is the cluster of young and middle-aged female riders of conventional owned bikes. These riders do no wrong: only 0.2% of them held a phone to their ear, nor was another secondary task observed. They do not wear additional safety equipment, commit very few rule violations, and do not have at-fault conflicts.
Cluster 4 is the cluster of older riders; females make up about one-third of the members. 12% of members of this cluster used electric vehicles. Some of this cluster's members behave "subjectively cautions": they do not perform secondary tasks; 20% wear a helmet, 8% wear reflective or fluorescent clothing. They sometimes commit rule violations: 1.6% use the pedestrian path and 3% the left side of the street; few have at-fault conflicts with pedestrians (0.9%) or other cyclists (0.2%).
The final fifth cluster is characterized by safety equipment use: 89% of members of this cluster wear a helmet and 30.2% reflective or fluorescent clothing. Only slightly more males than females are grouped into this cluster of younger to middle ages riders. All riders in this cluster owned conventional bikes. They very seldom engage in secondary tasks, commit rule violations or are found in at-fault conflicts.

4 DISCUSSION

Compared to older German observations, secondary task engagement dropped overall and for all observed tasks. Banned phone use was negligible. This might indicate an actual decline in secondary task engagement in German bicycle and e-scooter riding. The numbers of helmet wearing were comparable to the recent other German studies.
We found that secondary task engagement was least often found in mixed traffic and most often on the combined cycling/pedestrian path. Nonmandatory safety equipment use was more prominent in older and female riders and commuter times. Here, vehicle type was a significant predictor: e-scooter riders were less likely, users of e-bikes than conventional bikes were more likely to use additional equipment (mostly helmets), as were delivery workers. Traffic rule violations were often found in good weather, non-commuter times, and younger and male riders. At-fault conflicts were also found more often in non-commuter times, possibly indicating some compensatory behavior where riders are more rule-abiding when there is a higher subjective and objective chance of a crash.
Bivariate relationships between observed behaviors show a relatively straightforward pattern; riders who engage in risky behaviors also do so in others (secondary tasks and traffic rule violations) and are found in at-fault conflicts: these riders less often use additional safety equipment. On the other hand, riders who use extra safety equipment are less likely to be engaged in secondary tasks or commit traffic rule violations, except for those helmet-wearing riders who illegally use the car lane when a mandatory cycling path exists. Nevertheless, when looking at the multivariate clusters, these profiles become more nuanced: First, there are the "ordinary" or "pragmatic", with the most secondary tasks and least use of safety equipment that commit rule violations and are found in at-fault conflicts. A second group consists of users of "modern" vehicles (e-scooters and e-bikes), including delivery riders, also showing risky behaviors, but less than the first group. These two groups of predominately younger and middle-aged male riders seem to be the target group for road safety campaigns addressing their behavior. Campaigns targeted at these specific groups may help reduce risky behaviors.

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Cyclist Behavior to Avoid Vehicle Collisions Using Drive Recorder Videos

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Keywords: Car-to-cyclist collision, Cyclist avoidance behavior, Drive recorder

1 INTRODUCTION

Since bicycles travel at high speeds and are frequently involved in traffic accidents, reducing bicycle fatalities and injuries is one of the most important issues in traffic safety. In car-to-cyclist collisions, the perpendicular configuration occupies the largest proportion of these collisions. Driver responses in lateral intrusions of cyclists at intersections have been examined [1,2], focusing on the drivers' braking reaction time and the time-to-collisions (TTC). Cyclist behavior can also have a significant influence on car-to-cyclist collision occurrence. Cyclist behavior has been investigated in naturalistic conditions and using in-depth accident data. In addition, the videos of drive recorders provide useful information on the cyclist behaviors [3]. This study investigated cyclist behavior with the drive recorder of cars in near-miss incidents and collisions.

2 METHOD

To examine the cyclist avoidance behavior in emergency situations, car-to-cyclist perpendicular incidents were extracted from the near-miss database. The avoidance maneuvers of drivers and cyclists were classified into three types according to who initiated the avoidance behaviors: (1) Near-misses avoided by cyclists, (2) Near-misses avoided by car drivers, (3) Near-misses avoided by both cyclists and car drivers.

228 car-to-cyclist perpendicular conflicts of drive recorder were used in this research: 165 near-miss data were from Tokyo University of Agriculture and Technology; 63 collision data were collected by this research project from the Aichi taxi association and Nagoya taxi association.

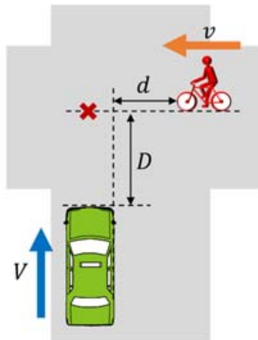


Figure 1: Parameters examined in car-to-cyclist perpendicular conflicts

In this study, the relationship between the cyclist behavior, the velocity and the distance of both the cyclists and car was examined. The car velocity was determined based on the output of the drive recorder with time. The velocity of the cyclists and the distance between the cars and the cyclists were measured based on video images. The car and cyclist traveling velocity and the distance to the collision point (path crossing point) are defined as V, v, D and d, respectively (Figure 1). The car and cyclist velocity as well as the car and cyclist distance to the trajectory cross point at the time when the cyclist can be visible from the driver (t_a) are denoted as V_a, v_a, D_a and d_a, respectively. Logistic analysis was applied to the probability of avoidance behavior of cyclist (w/ avoidance behavior 1; w/o 0) using the above parameters.

3 RESULTS

3.1 Cyclist avoidance behavior and its effectiveness

The number of near-miss incidents and collisions classified by cyclist and driver avoidance behavior is presented in Table 1. There are 85 cases of cyclist avoidance behavior: among them 31 cases are avoided by both cyclist and driver avoidance behavior, and 54 cases are which only the cyclist took an avoidance behavior (near-miss is successfully avoided by the cyclist's avoidance behavior instead of the car driver's avoidance behavior). On the other hand, the cyclist does not take avoidance behavior in 143 cases: among them the driver's avoidance behavior is observed in 80 cases, while the driver's avoidance behavior is not observed in 63 cases (collisions).

Figure. 2 shows the relationship of TTC_b and the car velocity V_b at the time of the car's brake onset t_b in the near-miss incidents with and without cyclist avoidance behavior. When the required acceleration of the car ($V_b/2\,TTC_b$) is higher than the braking performance limit (a = 5.2 m/s^2 [3]), the car cannot stop before reaching the collision point. The cases where cyclists do not take avoidance behavior are distributed in the right area of the car's braking performance limit ($V_b/2\,TTC_b < 5.2\ \mathrm{m/s^2}$), and car drivers can avoid the collision by car braking. Of the 85 near-miss incidents with cyclist avoidance behavior, 14 cases are where the cyclists are beyond the car's braking limit. These 14 cases would have resulted in a collision if the cyclist had not taken an avoidance behavior, indicating that cyclist avoidance behavior is effective in avoiding collisions.

Table 1: Number of cases with and without cyclist and driver avoidance behavior.

		Car driver		
		w/ avoidance behavior	w/o avoidance behavior	Total
Cyclist	w/ avoidance behavior	31	54	85
	w/o avoidance behavior	80	63 (collision)	143
	Total	111	117	228

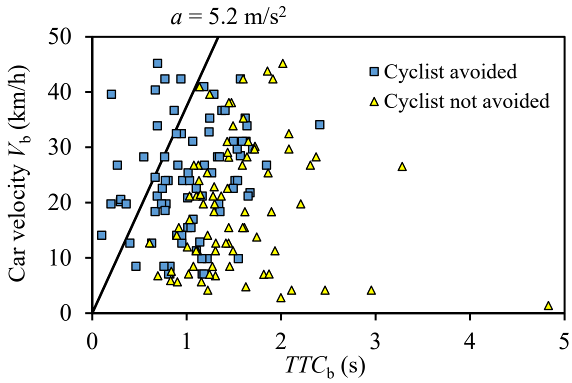
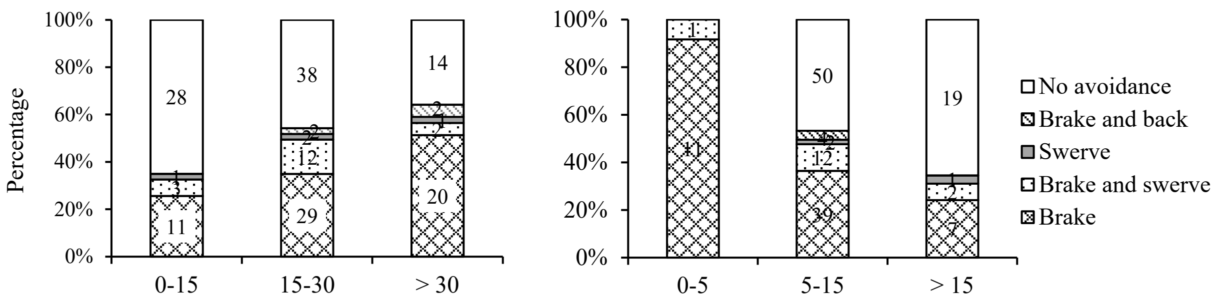


Figure 2: Relationship between TTC_b and the car velocity V_b at the time of brake onset t_b with/without cyclist avoidance behavior in near-miss incidents (the line shows the braking limit). Note: collisions are not included.

The percentage of the cyclist behavior with different car velocities V_a is shown in Figure 3(a). The percentage of avoidance behavior of cyclists increases as the car velocity increases. Among the types of cyclist avoidance behavior, the primary behavior is bicycle braking. Some cyclists use swerving or apply both braking and swerving to avoid collisions. In addition, 4 cyclists apply braking and reverse the bicycle to avoid accidents.

Figure 3(b) shows the percentage of the cyclist behavior with cyclist velocity v_a. The trend of cyclist behavior with the cyclist velocity is opposite to that with the car velocity. The percentage of the avoidance behavior of cyclists decreases as the cyclist velocity increases. Hence, cyclists tend to take avoidance behavior when the car velocity V_a is high and cyclist velocity v_a is low.



(a) Vehicle velocity V_a (km/h)

(b) Cyclist velocity v_a (km/h)

Figure 3: Cyclist avoidance behavior with car velocity V_a and cyclist velocity v_a when the cyclist is visible to drivers (t_a).

3.2 Cyclist velocity

The distribution of cyclist velocity at t_a in the cyclist avoided near-misses, cyclist not avoided near-misses, and collisions is shown in Fig. 4. The mean velocity in the cyclist avoided near-miss, cyclist not avoided near-miss and collision group is 9.9 km/h, 12.9 km/h and 13.5 km/h, respectively. The p-value of the mean velocity of the cyclist's avoided near-miss is significantly lower than that of the cyclist's not avoided near-miss and the collision (both $p < 0.001$). The cumulative distribution of cyclist velocity shows that the distribution of cyclist velocity in cyclist's avoided near-misses is smaller than the other two groups.

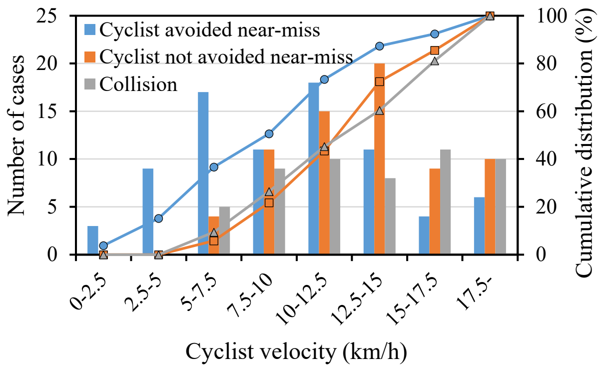


Figure 4: Cyclist velocity at the time when the cyclist is visible from the driver

3.3 Parameter determining initiation of avoidance behavior

The probability of a cyclist's initiating an avoidance behavior was expressed with explanatory variables in the logistic regression analysis. Car velocity V_a, car distance D_a, and cyclist velocity v_a at the time when the cyclist is visible were the primary parameters for determining a cyclist's initiation of avoidance behavior in near-miss incidents based on the p-value ($p < 0.001$).

$$P = \frac{1}{1 + \exp\left(-1.405 - 0.157\, V_a + 0.2476\, D_a + 0.1668\, v_a\right)} \tag{1}$$

In Eq. (1), the probability of cyclist's avoidance increases as the car velocity is higher and the distance between the cyclist and the collision point is smaller. Hence, a logistic regression was conducted using TTC_a instead of V_a and D_a. The probability of avoidance by cyclists using TTC can be expressed using two parameters as:

$$P = \frac{1}{1 + \exp\left(-2.5846 + 0.3048\, TTC_a + 0.1566\, v_a\right)} \tag{2}$$

The p-value of TTC_a is 0.0212, and v_a is <0.001, respectively. The prediction accuracy of the regression is 73.0% and 69.6% in Eq. (1) and (2). Basically, cyclists take avoidance behavior in emergency situation (small TTC) and when the cyclist velocity is low.

4 DISUCSSION

New findings are observed from drive recorder analysis for cyclist avoidance behavior in car-cyclist perpendicular conflicts. It is shown that cyclists took avoidance behavior based on the car's approaching velocity and distance. This is because cyclists judged whether to cross the street by recognizing the hazards based on TTC. Besides, cyclists also do not tend to take avoidance behavior if the cyclist's traveling velocity was high. This is probably because they are confident in crossing the street before the car arrives at the path crossing point.

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Personality traits, risky riding behaviors and crash-related outcomes: findings from 5,778 cyclists in 17 countries

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Keywords: Cyclists, personality, riding behaviors, road risks, self-reported crashes.

1 INTRODUCTION

The last few years have brought about a series of substantial changes for mobility on two wheels, especially if the impact of the COVID-19 pandemic is considered as a relevant fact for transportation dynamics [1,2]. Social distancing recommendations have promoted the use of individual transportation systems instead of massive transportations means. Consequently, riding a bike for urban trips has become increasingly prevalent in many countries [3-5].

Besides an opportunity to make urban mobility more active and sustainable, this panorama poses the challenge to prevent that, along with its growing use, bicycle crashes –and their consequences– might continue to increase. In this regard, recent studies have emphasized the role of individual differences and personality-related factors as potential issues influencing both cycling behaviors and traffic crashes suffered while riding [6,7].

2 METHODS

The core aim of this study, encompassed within the *Bike-Barometer 2021-2022* macro-project, was to assess the relationships among personality factors (approached from the "Big Five" paradigm), riding behaviors and self-reported safety outcomes of cyclists.

For this purpose, we used the data gathered form an extensive sample of 5,778 cyclists (*M*= 36.63 years; 59% males) from 17 countries, responding to an electronic questionnaire including: a set of demographics (e.g., age, gender); cycling trip-related factors (e.g., trip frequency and length); the *Cycling Behavior Questionnaire* (CBQ) [8], used to measure risky (violations and errors) and positive riding behaviors; the *Short Big Five Inventory* (BFI–S) [9], used to measure personality traits under the Big Five (OCEAN) approach; and the number of self-reported cycling crashes suffered during the last 5 years.

3 RESULTS

The bivariate findings of this study show positive and significant associations among personality traits and road risky behaviors. Namely, traffic violations and errors were negatively correlated to Openness (only for errors), Conscientiousness and Agreeableness, and positively with Extraversion and Neuroticism. Positive behaviors were negatively correlated to Neuroticism and positively with Openness (only for errors), Conscientiousness and Agreeableness. Notwithstanding, only two among the five personality traits addressed in the Big Five model (i.e., Openness and Agreeableness) were significantly correlated to self-reported cycling crashes.

Table 1: Bivariate correlations among study variables

	Study variable	Mean	SD	1	2	3	4	5	6	7	8	9	10
1	**Age**	36.63	14.71	--									
2	**Weekly cycling intensity**	6.16	5.97	.312**	--								
Personality factors (traits)													
3	**Openness (O)**	5.51	1.51	.130**	.144**	--							
4	**Conscientiousness (C)**	4.74	1.11	.307**	.197**	.461**	--						
5	**Extraversion (E)**	4.11	1.31	.159**	.027	.269**	.223**	--					
6	**Agreeableness (A)**	4.80	1.08	.224**	.104**	.428**	.516**	.178**	--				

7	**Neuroticism (N)**	3.49	1.18	-.175**	-.149**	-.016	-.159**	-.087**	-.119**	--			
Cycling behavior and safety outcomes													
8	**Violations**	.68	.58	-.153**	.147**	.012	-.108**	.045**	-.094**	.043**	--		
9	**Errors**	.50	.53	-.116**	-.072**	-.075**	-.183**	-.001	-.157**	.189**	.515**	--	
10	**Positive Behaviors**	3.01	.79	.142**	-.030*	.126**	.186**	.008	.193**	-.050**	-.368**	-.306**	--
11	**Cycling Crashes**	.77	1.31	-.001	.278**	.047**	-.007	-.006	-.053**	-.011	.246**	.239**	-.166**

Notes: * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

Also, hierarchical linear regression models were used to predict self-reported cycling crashes, on the basis of the study variables. Overall, it was found that gender (i.e., being a male) and cycling intensity are factors increasing crash likelihood. Regarding personality traits, it was found that Openness to experience (O) is the only factor increasing crash likelihood, while greater values in Extraversion (E), Agreeableness (A), and Neuroticism (N) were related to lower self-reported crash likelihood rates.

Finally, and as expected, both types of risky behaviors (errors and violations) significantly increased crash likelihood, while positive behaviors kept a negative and significant relationship to the number of riding crashes suffered by cyclists.

Table 2: Hierarchical regression model predicting self-reported cycling crashes based on individual factors, personality traits and riding behaviors.

Variable	Unstandardized Coefficients		Standardized (Beta)	t	Sig.	95% Confidence Interval	
	B	Std. Error				Lower	Upper
Model: ΔR^2= .149; *F*= 83.567; *p*< .001							
Gender[a]	.080	.035	.031	2.287	.022	.011	.149
Age	-.002	.001	-.023	-1.706	.088	-.005	0
Cycling intensity	.041	.003	.179	13.530	<.001	.035	.047
Personality factors (traits)							
Openness (O)	.051	.013	.061	3.939	<.001	.026	.077
Conscientiousness (C)	.009	.019	.008	.508	.612	-.027	.046
Extraversion (E)	-.027	.013	-.028	-2.082	.037	-.053	-.002
Agreeableness (A)	-.070	.018	-.059	-3.827	<.001	-.105	-.034
Neuroticism (N)	-.054	.015	-.050	-3.644	<.001	-.083	-.025
Cycling behaviors							
Violations	.268	.037	.123	7.173	<.001	.195	.342
Errors	.455	.041	.189	11.067	<.001	.374	.535
Positive Behaviors	-.108	.021	-.071	-5.206	<.001	-.148	-.067

Notes: [a] Ref. category= Male; Dependent Variable: Self-reported Cycling Crashes (5 years).

4 CONCLUSIONS

The findings of this study show how, apart from gender and cycling intensity, personality factors can act as significant predictors of crash involvement among active urban cyclists. Also, both risky and positive rising behaviors remain significant contributors to cycling crashes suffered by them.

These outcomes might help to understand the relationships among individual, personality and behavioral features of cyclists in relation to their self-reported cycling safety outcomes, as well as their potential link with road risky and positive behaviors preceding traffic crashes involving cyclists.

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Being safe by knowing how to behave? The subjective safety perception among migrants

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Keywords: migration background, cycling, infrastructure, perceived safety, mobility culture.

1 INTRODUCTION

In many countries, cycling is mostly known as a sport or leisure activity but unsafe in traffic. Cycling in traffic is one of the major safety concern and a main barrier for cycling in many countries (e.g. see in [1; 2]). At the same time, the quality of cycling infrastructure varies strongly between countries. When moving from a country with a non-existing cycling infrastructure to a country with cycling infrastructure, the bicycle as a means of traffic is very likely to raise interest. In the process of settling and influenced by a new environment, migrants usually start changing habituated behaviour and readjust norms and attitudes, what often cause the wish to participate in activities perceived as common behaviour [3].

Nevertheless, in Germany as a rather cycling-friendly country, statistics show significantly less cycling and bicycle ownership among migrants from non-western countries, especially among women compared to natives [4]. Aim of the study was to analyse the perceived safety of cycling from the view-point of migrants from non-cycling countries and subsequently identify the safety-related barriers to cycling.

2 METHOD

The focus of the study was on the associations immigrants have with bicycle use in Germany and how these are comparable with their experiences in their home countries. We conducted focus groups with migrants from Syria, Turkey, and Russia in Dresden and Munster in their native languages (see sample structure in table 1). In group interviews, supra-individual attitudes and collective behaviours can be recorded and discussed interactively [5].

To not make mastery of the German language a prerequisite for participation in the survey, the interviews were conducted in the three project languages Russian, Turkish and Arabic. For this purpose, one Russian, one Arabic and one Turkish native speaker with German language proficiency were selected and trained in the role of the interviewer in a one-day training course. An interview guideline helped the interviewers to maintain comparability between the different interviews. The guideline consisted of three topic blocks. Each topic block contained guiding questions, a checklist with important aspects that should be dealt with in the interview, as well as specific questions that could be asked at the appropriate point in the interview to cover important aspects of the interview.

In topic block A, we discussed mobility behaviour in the country of origin, differences in cycling between Germany and the country of origin, and a classification of one's own mobility type.

Block B discussed cycling in Germany. In the first question, we examined perceptions of cycling as a form of transportation in Germany.

In topic block C, we looked at bicycle initiatives. After explaining what an initiative is, the participants were asked whether they had ever received bicycle assistance in Germany and what type of assistance they would have found helpful.

2.1 Sample

Two survey cities were selected that contrast strongly in a number of parameters so as to be able to consider a variance in urban mobility culture [6]:

- Munster and
- Dresden.

Apart from a very different distribution of immigrants and their countries of origin among the regions of the Federal Republic of Germany [7], the infrastructural conditions in both cities vary greatly as well. Munster has been promoting cycling for years and is considered one of the most bicycle-friendly cities in Germany (cf. Fahrradklima-test 2020), which also reflects in bicycle use.
In Dresden, car driving and public transport exceed cycling as the primary mode of transportation by a wide margin. A public transport-oriented transport culture can be assumed [6].

The sample integrates migrants with an own migration experience from Turkey, Syria/Iraq and Russia in different age groups. The group interviews took place in Dresden and Munster. For this purpose, a maximum of five people ideally of the same gender and language group, but of different ages, were selected and invited to the two-hour sessions. All interviews were recorded in parallel by two audio devices. 55 people were invited; a total of 37 actually participated. Each participant received 20 euros compensation after the interview.

Table 1: Sample for all 10 focus groups in both cities. N = 37 persons.

Nationality	Gender	City		Total
		Dresden (n = 18)	Münster (n = 19)	
Turkish	Male	3	2[1]	5
	Female	4	2[1]	6
Arabic	Male	-[2]	5	5
	Female	5	4	9
Russian	Male	3	2	5
	Female	3	4	7

[1] mixed group
[2] Cancelled due to pandemic restrictions

3 RESULTS

A detailed qualitative analysis is still pending and will be finished in summer 2022. A basic content analysis of the interview transcriptions, points towards a positive view on traffic safety in Germany among migrants, mostly through the comparison effect between the experiences in their home countries.

The most mentioned aspects are rule compliance and the visible integration of the bicycle in the infrastructure. When it comes to individual prerequisites most participants reported a very low confidence in own rule knowledge and physical cycling skills, as most cycling experience dates back to the childhood and observation of the behavior of others.

The given cycling infrastructure is both inviting and intimidating at the same time but has a great potential to motivate novice cyclists to test the bicycle as a means of transport if the perceived knowledge- and skill gap is closed. Interestingly, the sample primarily attributes safety deficits in cycling to personal shortcomings rather than external, traffic-related problems.

4 CONCLUSION

In the presented study, the subjective safety perception of migrants who migrated from a non-cycling country to a rather cycling-friendly country was approached through group discussions. The results can help to understand entry points to empower future cyclists for safe cycling and provide them with a better access to the full modal split.

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Level of smartness and technology readiness of bicycle technologies affecting cycling safety: A review of literature

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Keywords: ICT on bicycles; cycling safety; smart bicycle; level of smartness; TRLs.

1 INTRODUCTION

Unlike motor-vehicle transport, the implementation of Information and Communications Technologies (ICT) and Cooperative Intelligent Transport Systems (C-ITS) in cycling has not been comprehensively investigated [1]. Cycling offers several benefits both to society and the environment and is one of the most sustainable and green transportation modes [2]. Many people worldwide have been switching to bicycles during the last decades, and this has increased even more due to the Covid pandemic [3]. Furthermore, the number of people who ride an e-bike is also rising [4]. Thus, the number of cyclists is increasing and, in turn, the number of cycling accidents is increasing too. For instance, in the Netherlands, one of the most cycling-friendly countries, 31% of all road fatalities in 2019 were cyclists (203 fatalities), while in 2020, it was 37% (229 fatalities). One-third of these fatalities were e-bike users [5]. Despite the constantly evolving landscape of cycling and electric bike adoption, applications of new technologies in bicycles are still immature.

In recent years, academic research on new technologies related to cyclists' comfort and safety is growing [6, 7, 8]. Furthermore, many studies focus on technologies affecting cyclists' road safety; however, it is unclear what type of technologies are implemented for bicycles. To the best of the authors' knowledge, a comprehensive review of such studies is lacking. Additionally, a clear definition of a "smart bike"- a concept gaining popularity nowadays, is missing in the literature. To address this gap, the objective of this paper is twofold: 1) to review the state-of-the-art technologies implemented in bicycles to improve cyclists' safety, and 2) to propose an original classification for the levels of smartness of newly emerging "smart bikes".

2 METHODOLOGY AND RESULTS

This study adopted a systematic methodology for the search and selection process [9] to make sure the full body of research on the topic is covered in the literature review, rather than snowballing and hand search, as well as to ensure reproducibility and transparency. A search query, focusing on new technologies associated to safety and different types of bicycles, including 29 keywords was developed and applied in Scopus and Web of Science databases, and the Google Scholar engine was used for grey literature. Only documents in English were included in the review and no geographical restrictions were applied. 1435 hits were screened, and only 36 were included in this review based on the specific predefined inclusion criteria.

Based on the reviewed literature, we propose a topology for the Bicycle Smartness Level (BSL) considering the dimensions of smartness as defined by [10], the automation levels of driving according to [11], and the Technology Readiness Levels [12]. With this topology, we wish to bridge the gap between the clear picture existing for automated vehicles and the less defined one in the more recently developed domain of smart bikes. Ideally, in this way, we can provide a foundation for a common language to be developed and used in future research to avoid confusion between the different capabilities and levels of smart bicycles.

More specifically, Figure 1 presents the BSL concerning the functionalities of these systems and their characteristics as follows: Level 0 contains the traditional bicycles, which cyclists pedal to use, and e-bikes with an electric motor and battery. Level 1 embodies systems that detect accidents and send emergency alerts as well as navigation systems. Level 2 consists of bicycles equipped with systems that can detect obstacles and warn cyclists to avoid a collision and cyclist monitoring system. Level 3 includes bicycles with cyclist assistance, including cruise control and automatic speed adjustment, to comply with the speed limits and reduce speed in critical locations. At this level Bike to Infrastructure (B2I) communication will be employed. Level 4 consists of systems that allow cyclists to receive notification of dangerous conditions through a connected environment where Bikes communicate with other Bikes (B2B), and Vehicles (B2V), achieving Bike to Everything (B2X) communication as well as braking assistance. Level 5 comprises an intervention ecosystem where, based on real-time data, governments or traffic authorities are able to influence user's behaviour, e.g., interventions in the operation of smart bicycles. C-ITS and advanced technologies are used as behavioural change instruments to achieve specific societal goals. With the development of the new technologies and the deployment of higher levels of smartness becoming a reality, bicycles and their systems are able to sense, process and act, providing advanced assistance to cyclists. Each level includes and builds on the features of the preceding levels. Note that the use of an electric motor is mandatory for speed interventions.

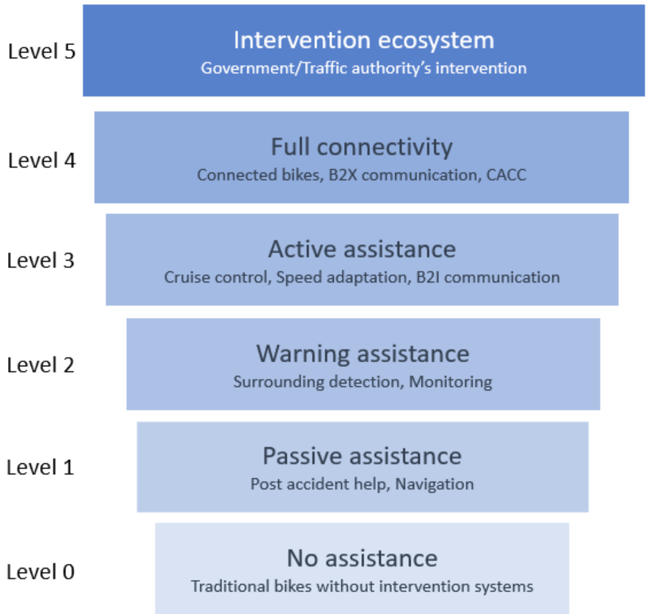

Figure 1: The proposed topology of the level of smartness on bikes

3 CONCLUSIONS

This study presents the current landscape of new technologies implemented on bicycles by reviewing studies focusing on applications and systems affecting cyclist safety. While there is a huge portion of recent literature concerning new technologies on bicycles, only a small part focuses on such technologies for safety purposes.

A topology of smart bicycle technologies is presented in this paper, aiming to give a clear image of the different levels of smartness. Based on the proposed topology, it is noteworthy that while research and prototypes reach up to BSL 4, the current state of the practice falls into BSL 2. The proposed BSL 5 is still theoretical, and will require the cooperation of various factors.

To assess the readiness level, we focused on the deployment of such technologies in the BSL - Level 5, since this is the level of interest for the future. As a result, we conclude that bicycle technologies currently fall into TRL 1 "Basic principles observed and reported" considering the maturity of technologies and lack of testing for the proposed systems.

The literature review showed that the majority of the studies investigated systems that mainly focused on warning systems for avoiding a collision, more commonly by using accelerometers/gyroscopes, LIDAR, sensors, and microcontrollers. These systems track obstacles such as vehicles and are limited to warning cyclists when they approach them. Although more than 50% of the studies included in this review employed e-bikes that could enable the implementation of speed intervention systems, the adoption of such systems was not investigated, demonstrating the lack of advanced technologies implemented in bicycles.

Among the reviewed studies, only a few collected and shared data through bicycle platforms, which clarifies that the level of communication technologies on bicycles is still underdeveloped.

To conclude, we would like to note that many studies developed smartphone-based systems, and currently, the B2B, B2V and B2I communication is mainly based on smartphones. This represents the current development in this domain and the efforts made to keep the cost for those systems on bicycles low. Thus, considering the rapid development of smartphones, an important question arises for future research: do we need new additional systems and technologies installed on bicycles to make cycling safer, or could this be achieved through smartphones since these devices are embedded with accelerometers, GPS, and wireless communication?

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Fork bending self-oscillation on bicycles influencing braking performance

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Keywords: bicycle, fork bending, tire oscillation, braking performance.

1 INTRODUCTION

This work deals with a fork bending oscillation phenomenon observed during hard braking on bicycles. The observed oscillation is described with experimental data and an attempt is made to understand the underlying root cause. Therefore, a multibody model consisting of the front wheel and the fork is employed to simulate a braking maneuver. The self-oscillation is replicated in simulation and implications on the brake process are derived from it.

Fork and tire oscillations on bicycles are rarely described in scientific literature. An oscillation due to tire resonance on high-speed motorcycles was described by Cossalter [1]. However, the mentioned speed dependence is not found in the present case under investigation. Klug et al. [2] were the first to report an oscillation of the fork inclination angle during braking. They noticed oscillations in the front wheel speed signals measured with a speed encoder mounted on the fork. Measurements of accelerometers and gyroscopes placed on the fork near the hub showed these oscillations on the forks inclination angular rate and vertical acceleration as well. This makes the phenomenon relevant for suspension and braking control. They also described the distorting effect of fork bending on the wheel speed signal and the wheel slip calculation derived from it.

This work tries to identify a root cause of the fork bending oscillation and investigates its influence on the stopping performance.

2 PROBLEM DEFINITION

During the authors previous work, measurements with an instrumented bicycle were conducted. Knowing about the effect from [2] attention was drawn to the phenomenon. The bicycle was equipped with an inertial navigation system (INS), an inertial measurement unit (IMU) mounted on the fork near the hub and brake pressure sensors. The INS gives accurate information about the bicycles over ground velocity as well as its spatial orientation. The IMU gives high bandwidth signals of the angular velocity and acceleration of the fork. On the other hand, the pressure sensor gives information about the braking process.

In Fig. 1 measurement data from a hard braking maneuver is shown. The rider was instructed to brake as hard as possible and as consistent as possible whilst tolerating a small amount of rear wheel lift. The upper plot shows the front wheel speed v_{f} as well as the over ground velocity v_{ref} from the INS. A superimposed oscillatory noise on the front wheel speed signal can be seen. The brake pressure p_{B} is also shown, the oscillation persists even when the pressure is held constant. The middle plot shows the angular velocity $\dot{\varphi}$ of the fork bending. Finlly the lower plot shows the measured acceleration in riding direction as well as the acceleration perpendicular to the road surface. This means that the fork is bending back and forth in riding direction and the hub is moving up and down relative to the road surface.

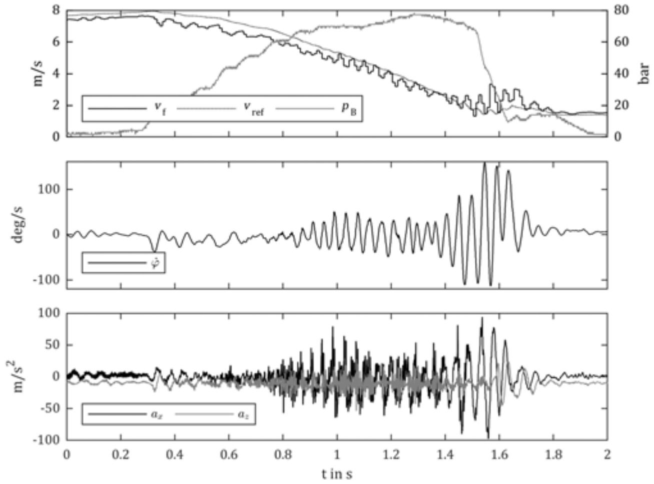

Figure 1: Measurement data showing strong additive oscillation noise. Taken from instrumented bicycle under hard threshold braking (rear wheel slowly lifting).

3 SIMULATION MODEL AND RESULTS

To understand the observed oscillatory motion a multibody simulation using a half bicycle model is set up. The topology is depicted in Fig. 2 and consists of the mass M suspended by the fork and the tire. The over ground velocity is assumed to be constant, thus the whole system is simulated in a moving coordinate frame. Consequently, only one-dimensional up and down movement of the mass is possible.

Using the results from [2] the bending of the fork is modelled as a rotary joint with the stiffness and damping coefficients c_F and d_F. The fork is tilted towards the ground with the caster angle φ_0. At the lower end of the fork the wheel is connected through a second rotary joint, representing the hub. The braking force is applied proportional to the brake pressure p_B by a friction brake as moment M_B between fork and wheel.

The wheel is modelled as a disk and has the parameters moment of inertia and mass as well as the undeflected radius r. There is a spatial contact force simulation between the wheel and the ground, allowing for separation. The contact force acts tangential and normal to the contact patch. The normal component F_N of the contact force is calculated from the deflection distance with the tire spring parameters c_T and d_T [5]. The tangential force F_r component is calculated using magic formula tire force model [3],[4] with F_N and the slip λ.

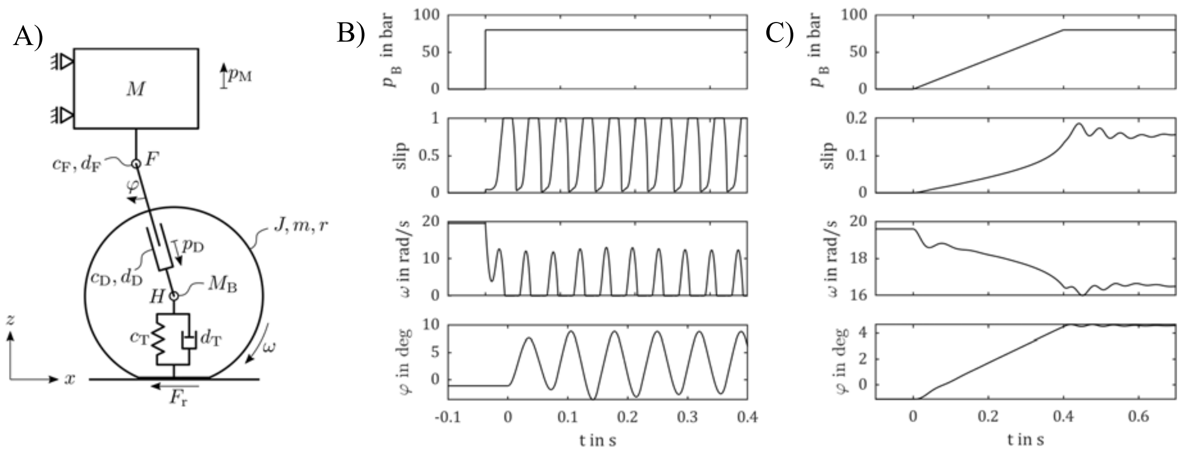

*Figure 2: **A** Topology of the used multibody simulation model. **B** Simulation results with step function 0-p_B **C** Simulation results with ramp 0-p_B, rising slew rate of $200\ bar/s$.*

The following two braking situations with constant bicycle velocity $v_0 = 7\ \mathrm{m/s}$ where simulated: First, a step from zero to $p_{\mathrm{B,krit}}$ is applied. With $p_{\mathrm{B,krit}}$ being the maximum theoretical possible brake pressure without wheel lock up. Second, the same step to $p_{\mathrm{B,krit}}$ is applied but with a rising slew rate of $200\ \mathrm{bar/s}$. The results of the two simulation runs are depicted in Fig. 2.

4 DISCUSSION AND CONCLUSION

The simulation shows self-oscillations on the slip λ, wheel speed ω and fork bending angle φ when the brake is applied with a step function. Contrary, when a rising slew rate is set, the self-oscillation is not kickstarted. A more in-depth analysis showed that the average braking force is 33 % lower if there is self-oscillation compared to the non-oscillating case. In fact, the step must be reduced to 88 % $p_{\mathrm{B,krit}}$ to prevent starting the self-oscillation.

The oscillatory motion was further analysed, there is a hopping motion present as depicted in Fig. 3. It can be described as follows: the fork is bend against the braking direction due to the braking force (1). The geometry of the forwardly inclined fork loads the tire and accelerates the mass M up (2). The tire is faster unloaded from the lifting mass M than loaded by the bending fork, it loses grip and jumps forward (3). Gravity accelerates the mass M down and causes the tire to grip again (4). The process (1)-(4) repeats indefinitely. From a Lyapunov viewpoint the oscillation is supposed to die down because all joints are dampened. Therefore, the hopping must be the energy source driving the oscillation.

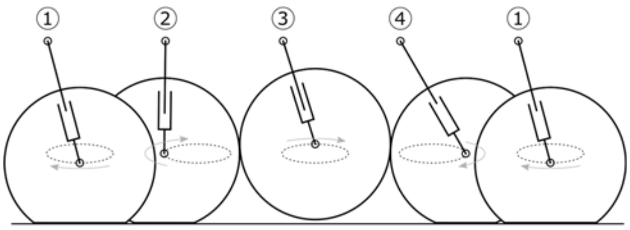

Figure 3: Visualization of the observed fork bending oscillation in the multibody simulation. There are two superimposed motions, the fork oscillates back and forth (2, 4) and the tire bounces up and down (1 ,3) resulting in a hopping motion.

In this work the experimental observed self-oscillation was replicated in simulation making in depth analysis possible. It was shown that the stopping potential is negatively affected by the oscillation and the underlying hopping mechanism was described.

Future research includes active means to reduce the fork bending itself or its detrimental effect on braking performance, for instance with active brake pressure modulation. Also, passive means of oscillation suppression are of interest, such as geometry changes or additional dampers. The fork and tire bending parameters will be measured in detail to enhance the simulation.

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A Tilting Trike with Rider Tuneable Stability and Handling for Improved Safety

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Keywords: Tricycle, Tilting, Tuneable, Stability, Handling.

1 INTRODUCTION

The potential advantages of tilting trikes have been tantalizing for years: they can lean like a bike so that they do not have to be low, wide, or slow in turns; and they can keep the rider upright like a trike when stopped or going slow.

Implementing this functionality, however, has been somewhat problematic. Many tilting trikes have been built in which the extra wheel only offers some redundant traction, in the case of inconsistent friction with the road surface. Some have been built with a so-called "tilt-lock", in which the third wheel can also act as a kickstand to hold the trike rigid when stopped.[1] A few tilting trikes have been built with sophisticated sensors, actuators, and control algorithms to assume the proper tilt angle in every situation,[2][3] and the motorcycle press breathlessly announces the latest patent filings in this area from major motorcycle manufacturers.

Figure 1: The working prototype in "rigid" mode keeping itself upright.

2 GENERAL DESCRIPTION

We demonstrate a tilting trike design in which the third wheel serves those first two purposes, plus it allows the rider to tune the vehicle roll acceleration without the expense, complexity, and weight of sensors, actuators, power sources, or dampers. Decreasing the roll acceleration makes the handling more docile and manageable, which can be especially helpful when traveling slowly and the weave instability, a relatively slow (0–4 Hz) oscillation between leaning left and steering right, and vice versa, is at its most unstable,[1] and this change in roll acceleration is accomplished only by varying the geometry of the tilting linkage, which can be actuated by hand.

Figure 2: The working prototype in “tilting” mode leaning against a wall.

3 CONFIGURATION

The initial working prototype features a delta wheel configuration, moving-bottom-bracket front-wheel-drive, to simplify the drive train, and aggressive recumbent seating, to minimize aerodynamic drag. New riders found it very difficult to master in purely free-tilting mode, when it acts exactly as the equivalent bicycle would. When halfway between free-tilting and rigid-trike, however, the roll acceleration is decreased, and riders found it much easier to ride.

The tilting mechanism is not tied, however, to the delta wheel-layout configuration, front-wheel-drive, or recumbent seating. A tadpole, rear-wheel-drive, cargo trike with upright seating is just as feasible.

4 IMPLEMENTATION

A linkage enables the rider to vary the tilting mechanism geometry, and as that geometry varies, the trajectory that the seat takes as the trike tilts varies, as shown in figure 3. At one extreme, the seat follows nearly the same trajectory it would if there was only one rear wheel, as with a bicycle. At the other extreme, the seat rises as the trike tilts, and gravity tends to pull it back to straight upright, as with a rigid tricycle.

In between these two extremes is a smooth and continuous variation of behaviour, and the rider can choose how quickly or slowly the trike tilts to suit the current riding conditions.[4]

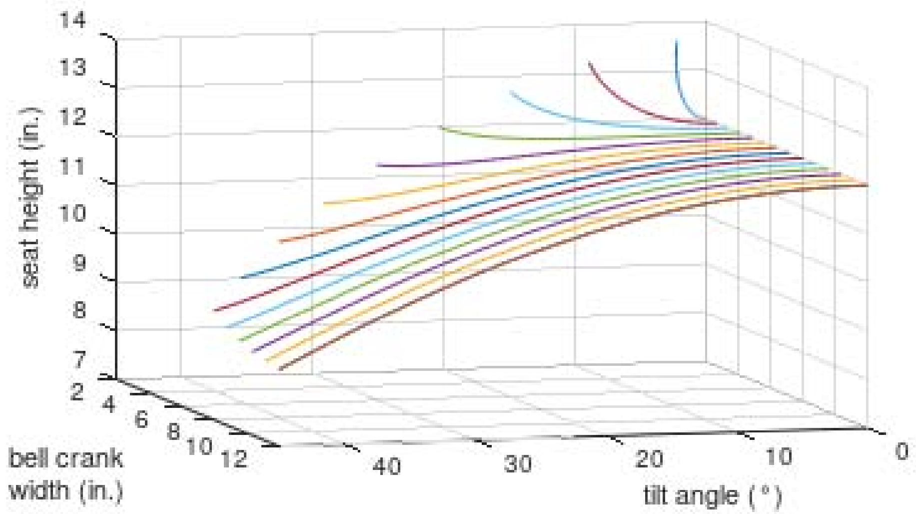

Figure 3: How the seat trajectory changes with tilting linkage geometry.

5 EXPECTED RESULTS

We will present the next iteration of this tricycle design that is more suited to consumer city biking and demonstrate the low-speed stability compared to a similar bicycle. The moving bottom-bracket and recumbent seating worked well for a proof-of-concept but would have limited appeal and utility in the general population. Instead, a version more similar to the standard European city bike will be easier for existing riders to adopt when they want or need a little help with balance.

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Bicycle simulator study with older adults: feasibility study

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Keywords: bicycle simulator, older adults, simulator sickness, familiarisation training, cycling dynamic.

1 INTRODUCTION

This feasibility study reports on the first experimental experiences with the BASt bicycle simulator. Since older cyclists represent an important target group in road safety due to their increased vulnerability [1, 2], both cyclists aged 65 and over (experimental group: EG) and, by way of comparison, middle-aged test subjects aged 25–50 (control group: CG) were included in the study.

The study aims to gain initial insights into the prerequisites, possibilities and limitations for using the bicycle simulator to observe cycling behaviour. In addition to the actual test ride the three preceding practice rides were also evaluated.

A comparable study with older adults has already been conducted with the BASt car simulator [3].

2 METHODS

2.1 Procedure

After the introduction, the subjects answered the pre-questionnaire about their 'real' cycling behaviour. Before the test ride they cycled three short practice rides (2–3 minutes) to become familiar with the bicycle simulator. During the breaks in between, the subjects answered a short questionnaire about their experiences. The test ride took place in a more complex urban scenario with several critical traffic scenes and lasted about 7–15 minutes. At the end of the procedure (Figure 1) the subjects answered the post-questionnaire for a final assessment. The whole procedure lasted about 1–2 hours.

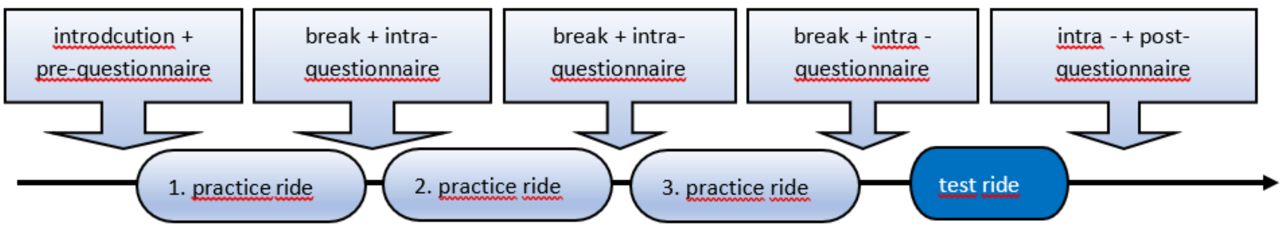

Figure 1: Procedure

2.2 Bicycle simulator

A static bicycle simulator was used for the study, which was developed by the Würzburg Institute for Traffic Sciences (Würzburger Institut für Verkehrswissenschaften, WIVW), as well as the SILAB simulator software. A 'real' Cube trekking bike equipped with sensor technology serves as a mockup (Figure 2). The mockup is mounted on a passive slightly movable carrier plate with the front wheel resting on the steering bearing and the rear wheel attached to the actuator. The virtual environment is presented to the subjects via ten large-format displays that allow a 300º horizontal and a 100º vertical field of view. Via headphones, the test person can hear the driving noises of other road users, background noises and also navigation announcements and instructions from the test guides (via microphone).

Figure 2: Bicycle simulator in front of 10 large-format displays

2.3 Data collection

For data collection, several questionnaires (subject's view / self-assessment) were used in addition to behavioural observation (observer's view / external assessment) and recording of cycling (speed measurement). The following aspects were central to the evaluation: drop-out-rate, simulator sickness, cycling performance, cycling experience, speed, cycling errors, assessment of the face validity, 'immersion' in the virtual world and self-assessment to 'real' cycling behaviour.

2.4 Sample

The sample comprised 35 older cyclists in the EG (age range: 65–89 years; M = 72.43 years / 65.7 % male; 34.3 % female) and 31 middle-aged cyclists in the CG (age range: 25–50 years; M = 38.42 years / 48.4 % male; 51.6 % female). Eleven subjects from the EG are 75 years of age and older.

3 RESULTS

The evaluation of the pre-questionnaire containing questions on 'real' cycling behaviour reveal age-typical differences between the two study groups: compared to the middle-aged, the older cyclists described themselves as slower and more cautious cyclists who avoid riskier cycling conditions. However, the older subjects more often stated that they regularly undertook longer cycling trips over 20 km.
The drop-out rate differs considerably between the two study groups. About half of the older subjects (n = 17) broke off the study prematurely; among the oldest subjects (≥ 75 years), the drop-out rate even amounted to 72.7 % (n = 8). In contrast, only 2 middle-aged subjects (6.5 %) had to drop out of the study prematurely. Half of the older subjects already dropped out during the first, short practice ride; mainly due to problems with handling the bicycle simulator. Drop-outs as late as during the test ride were due to intolerance (simulator sickness).
A comparison of the remaining study-completers (EG: n = 18; CG: n = 29) shows that the older subjects of the EG rode significantly more slowly than the subjects of the CG during the test ride. The cycling performance of the older subjects compared to the middle-aged subjects was rated significantly worse in the external assessment by the observers. This difference was not found in the self-assessment. There are age-typical differences in the cycling errors of the two study groups, whereby the relatively high total number of errors in both study groups can be attributed to dynamics of the bicycle simulator that could yet be improved. On a positive note, the study can provide initial indications of successful 'immersion' in the virtual world.

4 RECOMMENDATIONS FOR FUTURE STUDIES

For future studies, two approaches are expected to reduce the high drop-out rate among the older. On the one hand, a more comprehensive familiarisation training with a slower and more systematic build-up of the level of difficulty could better meet the needs of older subjects. It is recommended to first concentrate on the group of older subjects between 65 to 74 years. On the other hand, further optimisation of the simulated cycling dynamics with regard to steering, braking and speed could reduce the drop-out rate by minimising the need for adaptation. The first approaches to solving this problem can already be demonstrated. For future experimental road safety studies, it is necessary to first carry out a systematic validation study through comparison with 'real' cycling behaviour.

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The final report of this study has not yet been published.

Cycling Safety Data Augmentation in the Urban Environment: A Barcelona Case Study

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Keywords: Cycling accidents, Infrastructure, Circulation spaces, Data augmentation, Barcelona (Spain).

1 INTRODUCTION

Cities plan to revitalize sustainable transportation, with a key emphasis on cycling. However, cities need to provide safe environments for cyclists through better infrastructure design, education programs, or other interventions to increase cycling numbers, as safety concerns greatly discourage people from cycling [1]–[3]. Thus, cities' strategies aim to protect and improve the safety of those who cycle [3], [4].

Here, cycling research contributes to understanding cycling and what factors related to the individual, the bicycle, and the surrounding environment, influence the risk cyclists face. Objective cycling safety goals are to i) decrease the outcome severity of accidents involving cyclists and ii) decrease the overall number of accidents. It is often based on accident records or police reports, yet most incidents are often not reported [5], [6]. Nevertheless, accident statistics are vital because they allow for factors such as demographic data and built environment to be analyzed to understand cyclists' risk of being involved or injured in an accident [7].

There is a worldwide need for more data about cycling accidents, their context, and the built environment's influence. Hence complete datasets are required. We make use of CYCLANDS – a collection of 30 datasets comprising 1.58M cycling accident records – to explore how other data and analysis can complement accident records. Thus, a subset of CYCLANDS was augmented to analyze circulation spaces around accident locations. We hope this takes a step in that direction, fostering the mix of authoritative and volunteered data and providing a more complete data set.

2 METHODOLOGY

This section explores how to augment cycling accident data with infrastructure data and extract knowledge from circulation spaces present in cycling accidents.

2.1 Cycling Accident Data

The 1,58M cycling accidents compiled in CYCLANDS include geographic scales ranging from city, region, or country-level data. Data was curated, with all observations including the accident outcomes, date, and geographic location. Other factors are also available for some of the datasets, including light, road, weather conditions, vehicle attributes, personal characteristics, and contributing factors.

This work uses the Barcelona subset of CYCLANDS, which includes 7.047 accidents from Barcelona, Spain, from 2010 to 2021. This subset includes the accident outcome severity, date, location (latitude and longitude), vehicles involved, age, gender. However, there is little to no information is given about the accident context, its potential causes, or the built environment where the accident happened.

2.2 Built Infrastructure Data Clustering

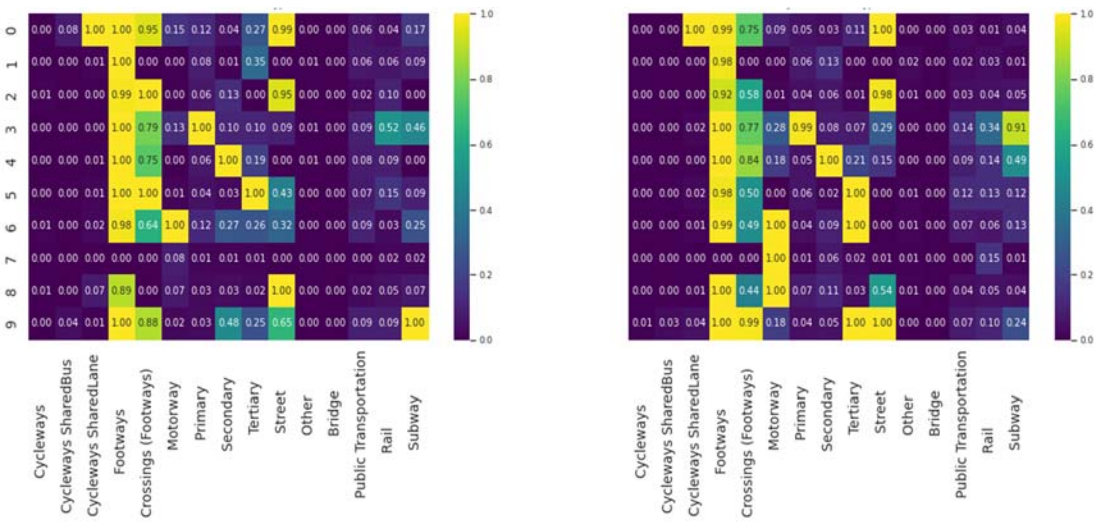
We aim to complement the available accident data by exploring and using other available data on the built environment surrounding each accident location. Specifically, we target to augment the available accident information by understanding the infrastructure where accidents happen and, in particular, the circulation spaces typical of cycling accidents (roads, sidewalks, cycleways, among others).

Thus, we use the latitude and longitude for each accident to download and extract data from OpenStreetMaps. We extract data around each accident location until a threshold distance ($25m$) and filter this data to extract only relevant elements related to circulation spaces. These circulation spaces refer to different road hierarchies (motorways, primary, secondary, tertiary, streets, bridges, or others), lanes dedicated to public transportation, sidewalks (footways and crossings), cycling infrastructure (dedicated cycleways, shared lanes with buses, and shared lanes), and rail infrastructure (rails and subways), totaling 15 different infrastructures extracted.

After extracting data on circulation spaces for the 7.047 accidents, we typify the usual environments where accidents occur. We employ Spectral Clustering (SC) [8] to identify types of cycling accidents circulation spaces that are a representation of the most standard locations where accidents happen in Barcelona involving cyclists. We run SC to cluster ten environments.

3 RESULTS

This section describes the results on the circulation spaces related to cycling accidents in Barcelona. Figure 1.a illustrates the ten Accident Environment Types (AET) found. Each row constitutes a type of environment, while columns indicate what types of infrastructures are present in each. The yellowish the cell, the higher the association between the AET and infrastructure types. For example, AET #1 only has Footways and Tertiary roads. In contrast, AET #2 has Footways, Crossings, and Streets, indicating an environment closer to an intersection between Streets and the pedestrian network. Another interesting fact is the Subway component (e.g. AET #9), which suggests that many accidents happen close to locations served by the subway where more activity (and confusion) may be present.



(a) (b)

Figure 1: Accident Environment Types (a) and City Environment Types (b).

Similar to accident locations, we applied the same procedure to locations in Barcelona, comparing whether environment types throughout the city would be identical to those of accident sites. Thus, we randomly sampled 15.000 points ($\sim 150\ points/km^2$) throughout Barcelona and applied the same clustering procedure. Figure 1.b shows Barcelona's City Environment Types (CET) and their composition. Compared to the AET, we see similarities but also crucial differences. First, most environments include crossings and footways, as expected. Second, some environment types are similar and appear in both AET and CET, such AET and CET

#0. Yet and more importantly, some types of infrastructure do not appear in the city analysis (e.g., AET #6 through #9), suggesting that environments where cycling accidents happen are different from those typically found throughout the city. Figure 2 shows the AET across Barcelona. As shown, we see the proximity between close accident locations and how different environment types are spread throughout the city.

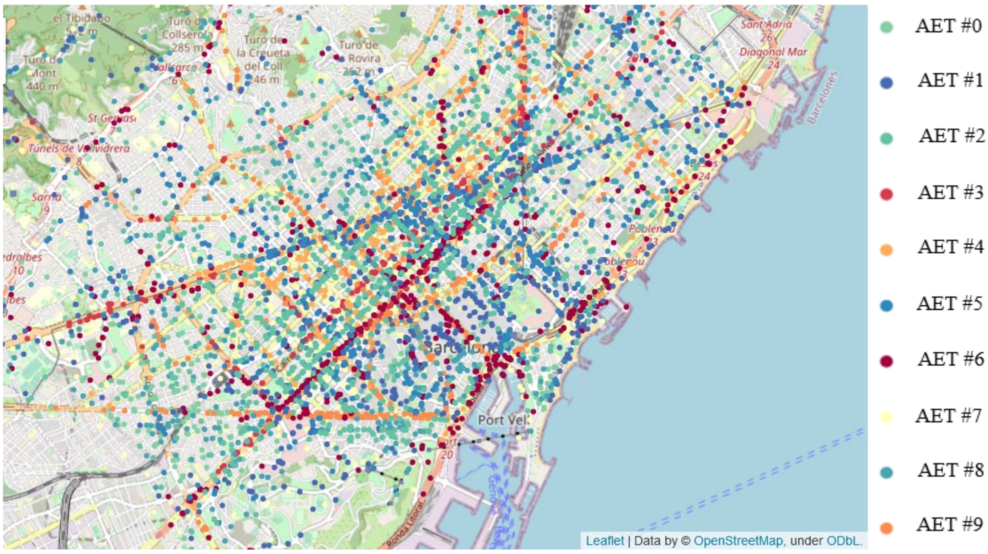


Figure 2: Accident Environment Types in Barcelona's accident locations.

4 CONCLUSIONS

In this work, we explore how data augmentation processes can be used to enrich existing cycling accident data. From cycling accident locations, we suggest a procedure to complete accident datasets with readily available data and how it can be used to analyze typical infrastructures associated with cycling accidents. Our results highlight differences between cycling accident locations and common city environments, providing insights into how the built environment might influence cycling safety. Such findings show the value of augmenting existing cycling accident datasets and collections using open data not found in the original dataset. Plus, the methodology here presented not only applies to the city of Barcelona but can be used to understand how different environment types might influence different cities and even find similarities between them. While such direct analysis brings insights about cycling accident locations, its applicability and usage in other modeling techniques and tools were not quantified, something we leave for future work.

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A Cyclist Warning System to enhance Traffic Safety - Development, Implementation & Evaluation in a Bicycle Simulator

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Keywords: safety critical events, cyclist warning system, warning model, bicycle simulator, user study.

1 INTRODUCTION & BACKGROUND

The aim of the research project RADimFOKUS was to develop and evaluate a cyclist warning system (CWS) prototype in order to prevent safety critical events (SCEs), such as accidents, for the specifically vulnerable group of cyclists and, in turn, contributing to an enhanced traffic safety for this sustainable and healthy mode of transport. The basic idea of the system was to warn cyclists in case a SCE is detected. Although research about CWS is rather scarce, first evaluations of such systems are promising [1]. Considering actual developments and trends, the CWS detects SCEs based on connected traffic information and is in a first step intended for the implementation in electrified bicycles (i.e. pedelecs), where power supply is provided by the integrated battery. In the scope of the project, we performed the following 3 stages, which are described in the current contribution: (1) Development of the warning model and user interface for the CWS prototype, (2) Development of a bicycle simulator and implementation of the CWS interface for user studies, and (3) First evaluation of the CWS prototype in the scope of a bicycle simulator user study.

2 WARNING MODEL AND INTERFACE OF THE CYCLIST WARNING SYSTEM

The core system has a comprehensive environment recognition to collect information from different sources like location broadcast messages from connected vehicles, localization data, sensor data, pedelec data, and historical data like traffic accident statistics. This information is analyzed in real time through an intelligent complex event-processing (CEP) pipeline to fast and reliably detect a potential SCE.

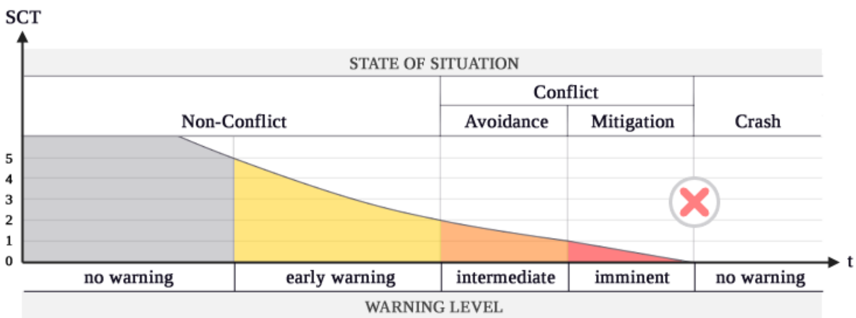

Figure 1: Warning levels depending on the derived SCT until a crash scenario happens as long as there is no intervention from the cyclist adapted from [2].

To inform a cyclist about a detected SCE without distraction, it is important to present the information timely, that means at a time when a reaction is still possible. For this purpose, a safety cushion time (SCT) based on the work from [3] was calculated and adapted for cyclist usage. The SCT depends on the time to collision, the reaction time and the time required for an emergency break. Following this, a warning level can be derived from the determined SCT value. As depicted in Figure 1, there are three warning levels ranging from early warning to imminent danger. If the warning level ‘imminent’ is reached, the cyclist should not be distracted by presented warnings anymore as at this time, all cognitive resources are needed to appropriately react to the SCE in order to prevent a crash (e.g., braking, steering). According to the model, intermediate and early warning intervals are appropriate to present warning information, because reactions to avoid a crash or SCE are still possible. Warnings against detected SCEs are pre-calculated based on the described warning model and presented to the cyclist. In order to present warnings in a usable, comprehensible and non-distracting manner, we combined 3 modalities indicating warnings: A visual signal is presented on a smartphone display. Simultaneously, an auditory warning occurs via alerting sounds (presented by speakers that may be integrated in the helmet), and tactile warnings are conveyed by vibration of the handles. All 3 warning modalities involve a direction indicator to allow for a rapid and directed response. Furthermore, the trimodal warnings are presented with higher frequency the closer the SCE according to the warning levels.

3 DEVELOPMENT OF A BICYCLE SIMULATOR

As a tool to test the CWS in a comprehensible, comparable and safe manner, we developed a bicycle simulator. In the simulator setup, the users sit on a chair and may either experience a 3D scene through VR glasses or on a monitor. We designed scenarios representing typical traffic situations in an urban environment and captured the braking responses to SCEs via game-controllers that were attached to a handlebar mounted on a table (Fig. 2a). For the custom scenarios, an editor was developed to easily create paths and location based parameter annotations to compute realistic driving behaviors for both, the bicycle and the cars, with the help of a one-track model. Fixed paths were used to ensure the comparability of users' reactions to the scenarios (Fig. 2b).

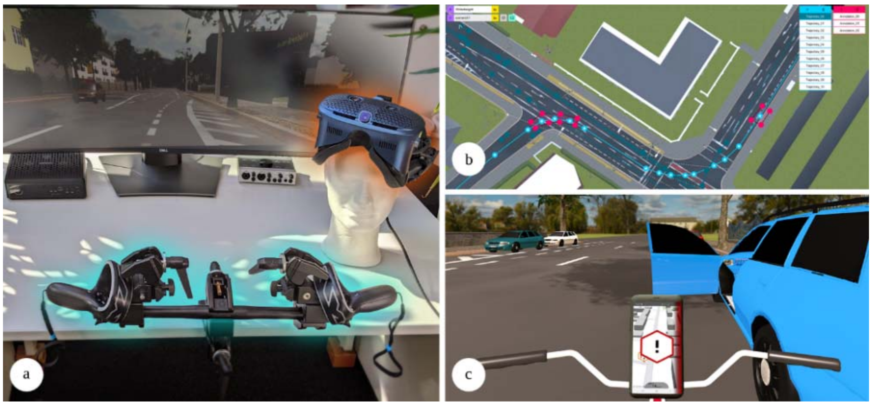

Figure 2: a) Test-setup with monitor, VR glasses and a customized handlebar; b) Editor for the scenarios; c) 3D scene as experienced by the user with visual warning signal presented on the smartphone interface.

The previously described warning levels were implemented as part of the computed paths. The visual signal was integrated on a smartphone as part of the 3D scene (Fig. 2c), the acoustic signal was presented with speakers and the haptic signal was integrated in the handlebar. For the evaluation of different combinations of signal modalities, each modality could be potentially enabled or disabled in the simulator. For each test drive, a set of relevant variables (e.g., brake reaction) could be automatically logged for subsequent analysis.

4 USER EVALUATION OF THE CYCLIST WARNING SYSTEM PROTOTYPE

For a first evaluation of the CWS, we conducted a bicycle simulator study addressing the following research objectives: (1) User assessment of the CWS interface and safety-related aspects when riding with vs. without CWS, and (2) Comparison of elderly (known to be specifically vulnerable) vs. younger cyclists. Accordingly, we investigated a 2x2 mixed design comprising the experimental within-factor CWS (test block with vs. without CWS) and the quasi-experimental between-factor age (younger versus elderly cyclists). In sum, $N = 65$ participants took part in the study involving $n = 32$ elderly ($M = 66$ years, $SD = 8$) and $n = 33$ younger adults ($M = 24$ years, $SD = 5$). In the study, participants experienced two blocks of a number of short test drives in the above described bicycle simulator environment in a balanced order. Amongst mainly uncritical situations, each block involved 3 SCEs (presented twice per block) with high relevance in the context of cycling: (a) Right turning truck with cyclist in blind spot, (b) intersection with obstructed view, and (c) opening door of a parking vehicle ('dooring'). Participants were asked to indicate perceived criticality for each experienced SCE and feeling of safety for both blocks. Additionally, we applied questionnaires addressing interaction comfort, appropriateness of signal timing, and usefulness of warning modalities. For safety-related aspects, results of a mixed ANOVA revealed significantly better safety assessments for cycling with ($M = 2.34$, $SD = 0.11$) compared to cycling without the CWS ($M = 2.08$, $SD = 0.10$; $F(1, 63) = 7.79$, $p = .007$, $\eta_p^2 = .11$). Similarly, for perceived criticality (exemplary calculated for SCE 'dooring') we obtained significantly higher criticality ratings for rides without ($M = 4.11$, $SD = 1.16$) compared to rides with CWS ($M = 3.06$, $SD = 1.20$; $F(1, 63) = 30.87$, $p < .001$, $\eta_p^2 = .33$). The group of elderly assessed the SCE to be more critical ($M = 3.92$, $SD = 1.23$) than the younger ($M = 3.26$, $SD = 1.27$; $F(1, 63) = 10.01$, $p = .002$, $\eta_p^2 = .14$). The analysis of the assessments regarding the user interface showed generally positive ratings for the timing of warnings with no differences amongst age groups ($t(63) = 0.25$, $p = .400$, $d = 0.06$; younger: $M = 4.16$, $SD = 0.92$; elderly: $M = 4.21$, $SD = 0.86$). Consistently, perceived interaction comfort was rated to be rather pleasant without significant differences comparing younger ($M = 76.39$, $SD = 18.47$) and elderly cyclists ($M = 68.77$, $SD = 23.34$; $t(62) = 1.45$, $p = .076$, $d = 0.36$). For the usefulness of warning modalities, we obtained generally rather high ratings for the trimodal warning approach, consistently for both age groups ($M = 3.84$, $SD = 0.97$; $t(61) = 1.06$, $p = .147$, $d = 0.27$). Interestingly, the visual signal component ($M = 2.98$, $SD = 1.22$) received lower usefulness ratings compared to the acoustic ($M = 3.63$, $SD = 1.21$, $p = .006$) and haptic ($M = 3.88$, $SD = 1.24$, $p < .001$; $F(2, 126) = 10.36$, $p < .001$, $\eta_p^2 = .14$) warnings, regardless of age groups.

5 DISCUSSION

The current contribution aimed at the development and first user evaluation of a CWS prototype to enhance traffic safety for cyclists by setting up and implementing an appropriate warning model and designing a user-centred interface. Additionally, we built up a convenient bicycle simulator to perform first user tests evaluating the CWS prototype. The CEP was able to process data from different sources and to detect most SCEs in real time. For late detections, the latency information should be further investigated. The estimated positions of the SCEs in combination with the warning model produced appropriate results for warnings. As there were no warning models for cyclists available, we adapted a model from the context of passenger car driving [3], which should be validated by further studies in the context of cycling. Looking at the results of the CWS prototype evaluation, user assessments revealed good ratings for the user interface including appropriate timing of warnings and rather comfortable interaction. Results further suggest a trimodal design of warnings in the cycling context with further hints to prefer acoustic and haptic over visual signals if single modalities are applied [1]. Furthermore, we obtained promising assessments from elderly and younger cyclists regarding increased safety-related aspects. In sum, these promising results from first subjective evaluations should be supplemented by behavioural data (e.g., brake reactions or gaze behaviour) in order to get further insights in effects on traffic safety. For investigating whether results obtained from our bicycle simulator study are also stable over different test set-ups, future studies could be conducted using VR glasses or allowing free cycling in a dynamic simulated environment.

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Is the "Safety in Numbers" effect tied to specific road types? - A GIS-based approach

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Keywords: safety in numbers, road types, cycling volume, crash statistics.

1 INTRODUCTION

The "Safety in Numbers" (SiN) effect proposes that when the volume of cycling traffic increases, the number of crashes increases less (relative to the cycling volume). A recent meta-analysis supported the general idea of a SiN effect, but also highlighted the heterogeneity of its strength ([1], [2], also see [3]). The authors of this meta-study conclude that the SiN effect is stronger at the macro-level than at the micro-level, but bears no clear relationship to the quality of the cycling infrastructure. The mechanisms producing the SiN effect are still unknown. Possible explanations are (i) that safer street regulations and designs are more likely to exist in societies with more walking and bicycling; (ii) changes in the behavior of people walking or bicycling; or (iii) changes in behavior of drivers. However, all of these explanations have their shortcomings [4]. Additionally, some authors have argued that an increase in the number of crashes cannot be ruled out due to the increasing number of inexperienced or particularly risk-taking cyclists [5]. There appears to be little research on the question whether and how the SiN effect may be linked to specific road types featuring different combinations of speed zones and cycling infrastructures. Furthermore, the base rate of cyclists (i.e. the cycling volume) is a highly relevant factor when investigating the distribution of crashes throughout different road types [6]. In our research, we thus use a GIS-based approach aimed at testing the relation between the cycling volume and the number of crashes involving cyclists for roads featuring different speed zones and cycling infrastructures.

2 METHODS

This research is focused on Freiburg im Breisgau, Germany, a city of about 230,000 inhabitants. Amounting to 34 % of all traffic in Freiburg in 2016, cycling accounts for one of the highest proportions of the overall traffic across all German cities. Crash statistics were sourced from the German federal office of statistics (available at https://unfallatlas.statistikportal.de). We selected all cases involving reported crashes of cyclists with vehicles, pedestrians, or other cyclists within the greater area of Freiburg that occurred in a five-year interval (2016-2020). The final analysis included 2,112 crashes. Cycling volume data were collected as part of the 'City-Cycling' campaign (https://www.city-cycling.org/home) during a three-week period in the summer of 2021. During the campaign, the participants' cycling activities were tracked and collected with a smartphone app. The entire dataset consisted of 69,228 trips by 4,012 individual cyclists (48% of them women, mean age group: 36-50 years), covering a total distance of approximately 400,000 km. The data was further processed and projected onto the city's Open Street Map (OSM) road network (for details, see [7]). The resulting cycling volume provides a solid estimate of the relative frequencies for each network category (i.e. streets, cycling paths, etc.). We extracted the network of all street and pathway segment lines in Freiburg accessible and unrestricted for cycling from OSM. We excluded all segment lines with a cycling volume of ten or less, with the reasoning that a street or pathway that is used by a lower number of cyclists in a three-week period is not relevant for an analysis of the SiN effect. We extracted the length, the speed limit, and the type of cycling infrastructure of each segment line. We subsumed similar instances into one category, but excluded, for example, streets that were not assigned with a speed limit in OSM. The final number of categories, the number of the respective road types, their average length, the mean estimated cycling volume, and the mean absolute number of crashes (in a 15 m radius) can be derived from the top part of Table 1.

3 RESULTS

We computed a Poisson regression model with the number of crashes at each segment as the outcome. Road type and cycling volume (divided by 1000 in the model to achieve a better interpretability of the parameter estimates), and an interaction term of both factors were included as predictors. The road segments showed huge fluctuations in their length, thus presenting a potential bias for the number of crashes. To account for this factor, we included the length of each segment as an offset-variable. See Table 1 for statistical details of the resulting model.

*Table 1. Numbers and means concerning several key variables, separately for all road types. The two right columns present the parameter estimates (and the standard error) as well as the Wald-Chi² for the main effects as compared to the reference category of roads with a speed limit of 30 km/h and no cycling infrastructure; and the interaction effects as compared to the reference category of 30 km/h * no cycling infrastructure. * = $p < .05$, ** = $p < .01$, *** = $p < .001$.*

	N	**Length in km**	**Cycling volume**	**Crashes**	**Estimate (SE)**	**Wald chi²**
Intercept					-1.15 (.04)	880.42***
Main effects						
Cycling volume					.96 (.05)	367.59***
No speed limit, cycling track	1,977	.15	343	.06	-1.91 (.11)	276.65***
50 km/h, cycling track	670	.06	245	.32	-.44 (.10)	19.61***
30 km/h, cycling track	113	.09	354	.42	-.70 (.25)	7.79**
No speed limit, pedestrian area	873	.11	81	.13	-1.13 (.11)	112.31***
50 km/h, cycling lane	582	.06	430	.44	.00 (.11)	.00
30 km/h, cycling lane	98	.06	457	.64	.00 (.26)	.00
30 km/h, cycling boulevard	103	.13	1229	1.21	.86 (.19)	21.28***
Living street (5-10 km/h)	134	.18	100	.22	-.96 (.24)	15.81***
50 km/h, no infrastructure	694	.09	220	.29	-.47 (.10)	21.70***
30 km/h, no infrastructure	1,758	.20	231	.53	.00	.
Interaction effects						
NA, cycling track * CV					-.74 (.15)	23.88***
50 km/h, cycling track * CV					.21 (.15)	1.96
30 km/h, cycling track * CV					.87 (.31)	7.75**
NA, pedestrian area * CV					.25 (.17)	2.12
50 km/h, cycling lane * CV					-.37 (.17)	4.54*
30 km/h, cycling lane * CV					.28 (.39)	.52
Cycling boulevard * CV					-.72 (.12)	33.04***
Living street * CV					2.01 (.73)	7.64**
50 km/h, no infrastructure * CV					.01 (.19)	.00
30 km/h, no infrastructure * CV					.00	.

The statistical model puts the number of crashes (as well as the interaction terms with the cycling volume) in relation to the respective reference category. In other words, this model may be less geared to investigate the strength of the SiN effect itself, but more to determine the relation between cycling volume and crash probability on different road types as compared to the reference category.

As expected, the model implies that a higher base rate of cyclists results in more crashes. Furthermore, the absolute number of crashes observed on most road types was significantly lower than for the reference category (30km/h speed limit, no cycling infrastructure). As exceptions, there were no differences to the reference category on roads featuring cycling lanes in both 30 km/h and 50 km/h speed zones, but a significantly higher number of crashes on cycling boulevards. The model shows negative parameter estimates of the interaction terms (i.e. a weaker increase of crashes on roads and paths with more cycling traffic) for cycling boulevards, 50 km/h speed zones featuring cycling lanes, and for cycling paths far away from roads. Somewhat surprisingly, we found that a higher number of cyclists led to further increases of the crash risk on living streets and on roads with a 30km/h speed limit featuring cycling tracks as compared to the reference category.

4 CONCLUSIONS

The results imply that the assumption of a SiN effect for cyclists may indeed depend on a path's or road's speed limit and cycling infrastructure. Noticeably, we found the strongest support for a SiN effect for those road types with a high average cycling volume (and cycling boulevards in particular). As an exception to this observation, the generally high cycling volume in 30 km/h speed zones featuring cycling lanes and cycling tracks appears to provide no or even a negative SiN effect. This finding requires further investigation. Further insights could be gained from investigating the collective behavior of cyclists on different road types: On roads without cycling infrastructure (and even on those featuring cycling lanes), cyclists may be more prone to ride one after each other. A high number of cyclists is already sufficient to prevent car drivers from overtaking them, for example due to oncoming traffic. However, cyclists riding next to each other or in flocks (for example on cycling boulevards) may block cars from overtaking entirely. In other words, it might be worthwhile to look into what kind of number provides safety in numbers. Another interesting question concerns a 'subjective safety in numbers': Cyclists may feel less vulnerable and less anxious to be overlooked by car drivers, the more other cyclists travel along with them. However, depending on the available or dedicated space, a condensed crowd of cyclists may also induce a fear of colliding with other bikers. Even when traveling next to other cyclists on a cycling boulevards (thus effectively preventing cars from overtaking), a closely following car "breathing down the cyclists' neck" may induce discomfort and stress.

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Evaluating Cycling Routes in a Bicycle Simulator

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Keywords: route attributes, route criteria, stress, safety, comfort.

1 INTRODUCTION

Although cycling becomes more and more popular, many people are still deterred from cycling by various aspects including a lack of perceived safety [1]. To offer preferable infrastructure and, hence, to better promote cycling, it is therefore crucial to examine how cyclists evaluate their routes, and to figure out what makes an infrastructure seem unsafe or unattractive.

Some studies have already identified important route criteria like safety or comfort, and have connected them to certain route attributes. High traffic volumes and cycling on no or poor cycling facilities are experienced as stressful by cyclists [2], [3], and they try to avoid these routes in order to reduce possible interactions with motor vehicles [4]. In contrast, a separated cycling facility, low speed, and low traffic volumes are evaluated as safe and stress-free [2], [5]. Furthermore, cyclists prefer comfortable routes, that is, routes with low gradient and few stops and traffic lights as well as attractive routes with a green and pleasant surrounding [6], [7].

Most of the studies investigated those criteria deductively, that is, the researchers analyzed the results theory-driven and in terms of predetermined criteria. In a previous study, we examined them in an inductive and qualitative approach that allowed us to collect criteria with the participants' individual wording and content [8]. We found that cyclists evaluate their route attributes in terms of Mental Comfort, possible interactions with other road users, Physical Comfort, the Ease of Use of the infrastructure, and the pleasantness of the surrounding. Safety and stress were found to be sub-aspects of Mental Comfort, whereas Interaction was associated with attention and concentration due to other road users. The term comfort, however, was mentioned by participants only in terms of physical comfort.

The aim of the present study is to validate these evaluation criteria found in our previous study, and to connect them to certain route attributes using the experimental approach of a bicycle simulator in combination with qualitative surveys.

2 METHOD

2.1 Procedure

The study is planned for June 2022 and will be conducted in the bicycle simulator at the Department of Traffic and Engineering Psychology at the Technische Universität Braunschweig.

The participants will cycle 13 sections that vary in certain route attributes (Table 1). Each participant will cycle each scenario, but in randomized order. After each scenario, the participants will be asked to stop in a side street and to answer a short survey about the experienced scenario. The survey will ask to rate how much the participant liked the section, to state good and bad aspects of the section, and to evaluate the section in terms of the criteria Mental Comfort, Interaction, Physical Comfort, Ease of Use, and the Environment. A description of the criteria is given to the participants as a handout so they can reread their meaning during the surveys.

2.2 Bicycle simulator and test scenarios

The bicycle simulator consists of a lady's bicycle standing on a motion platform that allows the bicycle to tilt slightly to the left and right. Twelve monitors assembled in a hexagon allows a 360°-view. Via noise-cancelling headphones the participant can hear simulated surrounding noises such as motor vehicles or birds. The simulator runs with the simulation software SILAB 7.0 [9].

The test drive will consist of 13 sections that vary in road class, the type of the cycling facility, the traffic volume of the motor traffic and the pedestrian traffic as well as in the gradient and the need to stop. A list of the scenarios is presented in Table 1. We focused on those attributes that both have been shown to highly influence cyclists' route choice, and that may vary in their evaluation on the criteria. Additionally, we needed to exclude other important attributes to avoid too many scenarios and, hence, a too long test ride.

Table 1: List of the scenarios used as sections in the test ride.

Nr.	Road Class	Cycling Facility	Traffic Volume		Gradient	Stop
			Veh/h/l	Ped/h		
01	Arterial	Advisory Lane	1000	100	-	-
02	Arterial	Advisory Lane	1000	100	-	Traffic Light
03	Arterial	Advisory Lane	400	20	-	-
04	Arterial	Cycle Path	1000	100	-	-
05	Arterial	Cycle Path	400	20	-	-
06	Arterial	Shared Footpath	1000	100	-	-
07	Arterial	Shared Footpath	400	20	-	-
08	Residential	none	400	100	-	-
09	Residential	none	400	100	3%	-
10	Residential	none	100	20	-	-
11	Residential	none	400	100	-	Priority
12	Park	Shared Footpath	-	100	-	-
13	Park	Shared Footpath	-	20	-	-

3 DISCUSSION AND CONCLUSION

We expect the evaluation of the sections regarding the criteria to be similar to the results of our previous study. That is, Interaction will increase and Mental Comfort will decrease with less separated cycling facilities, higher traffic volumes, and on arterial roads. However, the ratings of these two criteria might differ between volumes of pedestrians and motor vehicles, as high pedestrian traffic might be perceived as mentally strenuous, but not as unsafe or stressful. Sections with a gradient or stops should be evaluated as less comfortable, and the park should be evaluated positively regarding the surrounding environment.

However, one interesting aspect will be whether the criteria captures all relevant aspects that cyclist use to evaluate their infrastructure. Therefore, it will be interesting to see whether the overall rating on how much the participants like the section can be explained by the ratings of the criteria. Furthermore, the responses of the open questions that asks for good and bad characteristics of the section will either confirm or correct the criteria.

Using a bicycle simulator as compared to pictures and description as in the first study will validate the findings of our first study in a more realistic way that enables the cyclists to really experience these attributes. However, a bicycle simulator is not fully able to provide an experience like riding on a real bike. Additionally, we cannot include all relevant route attributes as too many sections would result in an unreasonable participation time.

Hence, the findings will be limited to the few examined attributes. However, our study will also provide the benefits of the experimental design of the simulator approach, that is, a controlled setting and conclusions about cause-and-effect relationships. The results will obtain further insights into cyclists' evaluation and preferences of routes and route attributes, and will help to understand what makes a route preferable.

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Enhancing cycling safety in Hamburg via PrioBike

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Keywords: cycling safety, intersection safety, warning technology, bicycle app

1 INTRODUCTION

Mobility has a vital impact on the quality of life in a city. Yet, traditional modes of car-centric transportation models generate large externalities that must be tackled by cities - such as congestion, noise and air pollution. The Free and Hanseatic City of Hamburg in Germany is striving for a mobility transition, making mobility more sustainable and environmentally friendly. The city wants to change the mobility behaviour by strengthening the means of transport that are causing less impact on the environment and climate. By 2030, the goal is to increase the share of cycling, walking and public transport to a total of 80 per cent of all routes travelled. Cycling, which is especially cost- and space-efficient, plays a crucial role here. More specifically, the share of all journeys made by bike should be increased by 25-30 per cent within this decade.

Within the framework of Hamburg's strategy of Intelligent Transport Systems (ITS) [1][2], the city fosters, develops and conducts ITS-projects that focus, amongst others, on cycling. In order to increase the proportion of cycling, it is essential to promote its attractiveness. A cycling infrastructure that ensures smooth and easy cycling within the city is vital for a competitive alternative to motorised private transport. Furthermore, people enjoy cycling when they feel comfortable and safe [e.g. 3]. The ITS-project PrioBike-HH follows this approach and addresses both topics: cycling comfort and safety. This abstract focuses on the aspect of safety.

2 OBJECTIVES

According to the Federal Statistical Office, 2,739 cyclists (including pedelec users) had traffic accidents in Hamburg in 2020. Three of these cyclists died. With 148 accidents per 100,000 inhabitants, Hamburg is above the national average. In general, the analysis of the accidents involving cyclists in 2020 shows that with 71.9 % motorized vehicles were the most frequent party involved [4]. One objective of the ITS-project PrioBike-HH is to increase the safety for cyclists in inner-city areas. For reaching this objective, the application of an infrastructure based warning technology, reducing the amount of accidents involving cyclists, is framed as one measure (see section 3). In order to define the functionalities of this warning technology, an extensive requirement analysis was conducted, including all relevant stakeholders. In the requirement definition phase, different roles were defined in order to include all relevant perspectives. These include cyclists, road users, motorized private transport, heavy goods vehicles, public transport, the police and further authorities within the Free and Hanseatic City of Hamburg. Some examples of user stories in the role of the cyclists are demonstrated in the following and are proving the importance of the project goal:

As a <cyclist> I want to <be noticed> in order to <cross the road safely>.
As a <cyclist>, I want to <be noticed> in order to <make other road users aware of me>.
As a <cyclist> I want to <be seen> to <avoid a collision with other road users>.
As a <cyclist> I want to be <protected from other road users> in order to <cross the road safely>.

As a <wrong-way cyclist> I want to <be noticed> in order to <cross the road safely>.

To increase cycling safety in inner-city areas and thereby the attractiveness of cycling in Hamburg, a range of different measures is framed in the project PrioBike-HH. The objective is tackled from two different perspectives. Firstly, from a city infrastructure view and secondly from the app, which is developed within the project. Both approaches will be presented in the following two sections, starting with the infrastructure.

3 INFRASTRUCTURE-BASED WARNING TECHNOLOGY

One objective of PrioBike-HH is the application of an infrastructure-based warning technology at intersections. Thereby the intersection safety is ought to be increased by preventing crashes between vulnerable road users (VRUs, such as pedestrians and cyclists/e-scooter) and the turning motorized traffic. The focus lies on the accident scenario with turning motor vehicle traffic crossing VRUs at inner-city intersections.

The information about cyclists crossing a road in the course of their route is to be implemented by introducing new technologies into the infrastructure. The warning message is triggered event-based when a cyclist is detected in a defined detection area, as shown exemplified in Figure 1.

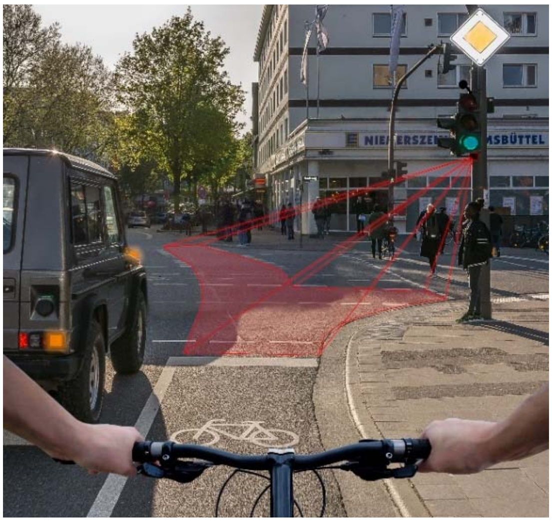

Figure 1: Example of a technology application to protect vulnerable road users © FHH, Kontrapunkt

Based on the requirement definition, a feasibility study will be conducted in order to define the specific technology to be applied. As a long term goal, the system should be rolled out at a range of high-accident intersections within Hamburg to increase the safety of cyclists and other VRUs.

4 UBIQUITOUS SYSTEMS FOR SAFETY

In addition to infrastructural safety measurements, PrioBike-HH is also eager to provide personal ubiquitous systems for cycling safety. In this scope, a ubiquitous system is considered as a system which interacts with cyclists in different ways. It also provides information, collects data and is based on a smartphone application.

As a first step, we are currently developing and testing an app which provides speed recommendations for cyclists. Combining the current position, speed and heading of a cyclist with a green light prediction for the next intersection, a speed recommendation is calculated. Following the recommendation, the cyclists will arrive at the intersection at a green traffic light and can cross it without waiting. This app will be the basis for further development and research that will focus on safety for cyclists. Besides infrastructural measures, safety can be increased by providing information.

4.1 Providing information via App

There are three main points on how cycling safety can be increased with ubiquitous systems:

Static information contain information which are constant for a certain time and not changing dynamically. Infrastructure information and information about black spots for accidents and near-accidents are considered as static information. Using this information, a routing can be provided which avoids dangerous sections as well as dangerous intersections and recommends safer routes. If no alternative routing is possible or wanted, cyclists can be warned when approaching a dangerous section or intersection.

Dynamic information is situation-based and not constant. Information about a vehicle at intersections turning close to a cyclist or approach them from behind for overtaking, can be considered as dynamic information. This type of information is more difficult to collect and needs sensors on the bicycle or road infrastructure. Different systems already provide this information, also cooperative ITS-messages can be used.

Collective information in this scope can help to homogenize the speed of cyclists. If cyclists on the same section follow the same speed recommendation provided by the PrioBike-App, the speed of these cyclists will be homogenized. They will form a group. This might increase safety for two reasons: If a group of cyclists is riding at the same speed, overtaking within the group is reduced which reduces critical maneuvers. Besides, a group of cyclists is better perceivable by car drivers and overtaking on narrow roads is reduced.

4.2 User interaction

Our system is based on smartphones and applications. However, the user interaction is not limited to a smartphone display. Since interacting with a smartphone while riding might have an impact on the safety, other forms of interaction are explored, such as visual, acoustic and haptic information transmission. Visual information transmission can be realized using augmented reality – information can be displayed in smart glasses, reducing distraction from traffic situations. Acoustic information transmission allows cyclists to keep their eyes on the road and can provide the aforementioned information via headphones, speakers or bicycle helmets with integrated speakers. Haptic information transmission is another possibility to reduce distraction. Smartwatches, vibrating handlebars or bicycle helmets with integrated vibration motors can be used as haptic devices.

4.3 Data collection

Ubiquitous systems interact with users, use sensors and are connected to the internet. Using this infrastructure, a significant amount of data can be collected. This data can be analyzed and used to gain more information about bicycle traffic, cycling safety and infrastructure conditions. GPS-data provide information about used tracks, driven speeds and speed changes. Sensors collecting data about acceleration, rotation and orientation on three axes deliver data for infrastructure analyses (e.g. surface), accidents and near-misses. The gained information can be used to warn cyclists and to conduct infrastructure improvements.

5 SUMMARY

Applying the measures described above within the project PrioBike-HH, the Free and Hanseatic City of Hamburg is eager to further improve cycling safety. These measures are currently in their design and development phases, but will be piloted within the city at different locations during the following months.

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Monitoring Bicycle Safety through GPS data and Deep Learning Anomaly Detection

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Keywords: cyclist safety, GPS trajectory data, Convolutional Neural Network, Surrogate measure.

1 INTRODUCTION

Cycling has always been considered a sustainable and healthy mode of transport. Moreover, during Covid-19 period, cycling was further appreciated by citizens as an individual opportunity of mobility. As a counterpart of the growth in the number of bicyclists and of riding kilometres, bicyclist safety has become a challenge as the unique road transport mode with an increasing trend of crash fatalities in EU (Figure 1) [1] [2].

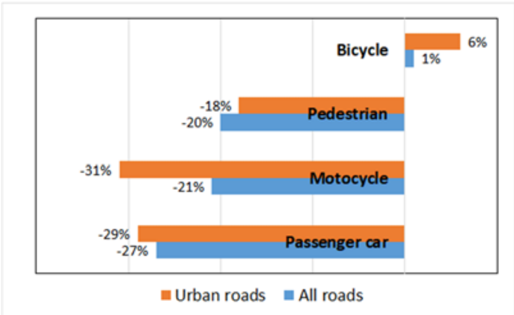

Figure 1: Trends 2010-2018 of Fatalities in crashes involving cyclists and other transport modes. Source: [2]

When compared to the traditional road safety network screening, availability of suitable data for crashes involving bicyclists is more difficult because of underreporting and traffic flow issues. In such framework, new technologies and digital transformation in smart cities and communities is offering new opportunities of data availability which requires also different approaches for collection and analysis.

An experimental test was carried out to collect data from different users with an instrumented bicycle equipped with Global Navigation Satellite Systems (GNSS) and cameras. A panel of experts was asked to review the collected data to identify and score the severity of the safety critical events (CSE) reaching a good consensus.

Anyway, manual observation and classification of CSE is a time consuming and unpractical approach when large amount of data must be analysed. Moreover, due to the complex correlation between pre-crash driving behaviour and due to high dimensionality of the data, traditional statistical methods might not be appropriate in this context. Deep learning-based model have recently gained significant attention in the literature for time series data analysis and for anomaly detection, but generally applied to vehicles' mobility and not to micro-mobility.

We present and discuss data requirements and treatment to get suitable information from the GNSS devices, the development of an experimental framework where convolutional neural networks (CNN) is applied to integrate multiple GPS data streams of bicycle kinematics to detect the occurrence of a CSE.

2 RELATED WORK AND PROBLEM FORMUATION

Deep learning-based algorithms, especially Convolutional Neural Networks (CNN) are widely used for anomaly detection in time series data [3]. Recently, deep learning and Convolutional Neural Networks (CNN) have been applied in road safety studies [4] and driving style analysis [5]. The convolutional autoencoders (CAE) allowed the extraction of valuable information from large quantities of complex and heterogeneous data, showed fast convergence speed due to the convolutional layers, and provides better performance to achieve volume, variability and velocity (i.e. big Data) [6]. The limitations of the existing works include that the observational studies applied on bicyclist safety mainly relay on traffic conflict techniques for video tracking from fixed positions. Few studies used trajectory data to identify SCE. To the best of our knowledge, this is the first work extending the use of deep learning CNN to extract features of the riding style of bicyclists from GNSS data and to detect anomaly events relevant for road safety assessment.

3 METHODOLOGY

3.1 Dataset Preparation

Dataset preparation includes both collection and treatment of GNSS data to extract features suitable to train and test the CNN model. For data collection, the source is an instrumented bicycle with GPS (Global Positioning System) and HD video system (Video Vbox Lite). Once data was recorded, different Python routines were applied to 1) improve the data quality, 2) interpolate for smoothing [7], 3) calculate derived parameters and 4) create the data set for training and testing the CNN. In the present application, speed (S) and heading (H) define the recorded time series in the GPS data, while longitudinal acceleration (LA), travelled Distance (D) and heading rate (HR), transversal acceleration (TA) and combined acceleration (CA) are derived.

3.2 BeST-DAD: the Proposed CNN application for Anomaly Detection

We call the complete scheme proposed for anomaly detection in the scenario of interest: '**B**icycl**e** **S**afety **t**hrough **D**eep learning-based **A**nomaly **D**etection' (BeSt-DAD). Best-DAD employs a 1-D Convolutional Autoencoder (CAe) as depicted in Figure 2. The input consists of a sequence of data samples, $X_1, X_2, \ldots$, generated at a frequency of 10 Hz and filtered as discussed in the previous Section 3.1. The generic X_i is a 6-tuple of values, i.e., $X_i = [x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}, x_{i6}]$ which represent the speed, heading, heading-rate, longitudinal acceleration, transversal acceleration and combined acceleration, respectively, and thus, the input data is 2-dimensional in nature, as shown in Figure 2. Nevertheless, we flatten the input data and consider it as a 1-dimensional sequence of type:

$$x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{21}, x_{22}, x_{23}, x_{24}, x_{25}, x_{26} \ldots \quad (1)$$

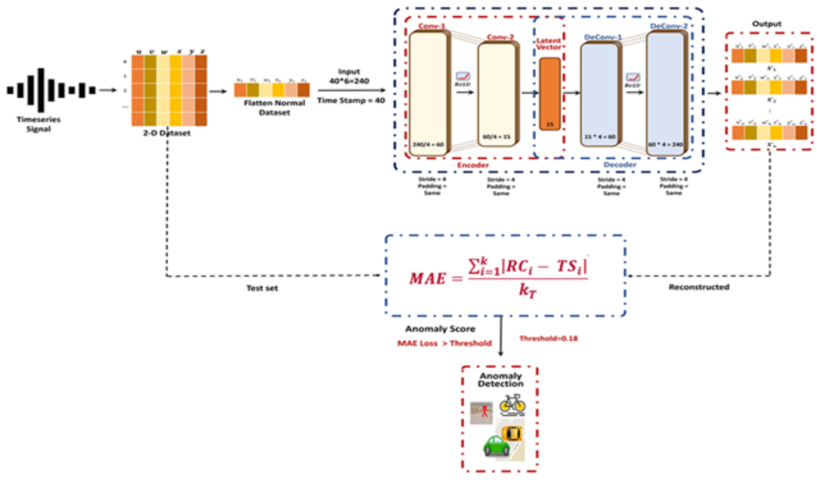

Figure 2: BeST-DAD scheme

4 RESULT AND DISCUSSION

For results, two scenarios have been selected for training and testing of the model: *A1)* Training and Testing CNN for each user, by using 80% of data for training and 20% of data for testing. *A2)* Training with the data collected by considering the entire dataset related to only one user and testing with the data from all the other users. Results for the validation scenarios (D, E, F), in terms of Recall, Precision and F-score, are presented and compared with the reference results for the two training approaches (A1, A2), for different thresholds (T) and time window sizes (TW). Results confirm the best performance for selected values of T and TW. Moreover, the application of the Svitzky Golay Filter (SGF) to the high-frequency time-variability of the cycling data improved mainly the Precision in the classification with a notable reduction of FPs. Finally, it is worth noting that merging speed and heading parameters resulted the main factor to improved performance.

5 CONCLUSION

Cyclists are vulnerable road users and their safety is still a challenge and a serious issue to be addressed. The effectiveness of the Artificial Intelligence technology and positive validation of the results with real data, makes the approach promising for the identification of location with potential hazard for cyclists in the wide urban road network by using mobility data that can be easily collected in smart cities and communities.

Performance evaluation of BeST-DAD for different model settings demonstrates that adding direction information (heading, heading rate, transversal acceleration) to the only speed parameters (speed, longitudinal acceleration), improved remarkably the capability of the model to detect anomalies. Data filtering by using SGF played an important role in reducing the FPs, as well.

The most relevant limitation highlighted by the study is the high number of FPs anyhow produced by the classification technique. The low precision is mainly related the actual phenomenon which is characterized by the cycling natural waving and speed variability and the occurrence of other factors other than CSE requiring sudden changes in riding (e.g. traffic signal, potholes, etc.)..

Finally, it is worthy to remark that CSE identification and spatial clustering may be used as first level network wide road safety assessment to be followed by targeted inspection to identify the actual need of remedial actions and priority as depicted by the most recent EU directive for Road Infrastructure Safety Management [8].

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Analyzing the impacts of built environment factors on vehicle-bicycle crashes in Dutch cities

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Keywords: safety, built environment, land use design, proximity to facilities, Hurdle Negative Binomial model.

1 ABSTRACT[1]

Cycling safety policy and research have mostly focused on cycling infrastructure, cyclists' behavior, and safety equipment in the past decades. However, the role of built environment characteristics (BECs) in the safety of cyclists has not yet been fully examined. For the Netherlands, this is rather surprising given the significant modal share of bicycles in daily trips, the importance attributed to urban spatial planning, and it being one of the most planned countries in the world. Despite the considerable improvements that have taken place in traffic safety over the decades, the (actual) number of cyclist deaths between 2011 and 2020 increased by on average 2% per year; the cyclists had a major portion of traffic death (followed by passenger cars); also, almost one-third of traffic death happened in built-up areas (about 25% of fatalities occurred on 50km/h roads in urban areas) in this period [1]. Considering the aim of construction of on average 75,000 new homes per year until 2025 [2], as well as promoting bicycle use in as a healthy and sustainable mode of transport in the Netherlands [3], understanding the relationships between the BECs and cycling safety is invaluable for improving the safety of cyclists.

BECs are usually represented by indicators called "5Ds", namely (population) density, (land-use) diversity, (land-use) design, distance to transit, and accessibility to destinations [4]. Different BECs lead to an increase or decrease in the number and probability of crashes as they contribute to variations in exposure, speeds, and conflicts between different mode users [5-7]. Previous research has shown correlations between population and employment density [8, 9], as well as density of residential [7, 9, 10], commercial, and educational land use classes [9, 11] on the occurrence of vehicle-bicycle (V&B) crashes in the areas, even after controlling for exposure. Moreover, land-use diversity [10, 12] and proximity to facilities such as transit stops and commercial and service locations were shown to increase the risk of V&B crashes [9, 13-16].

Disregarding the collective effects of the abovementioned BECs can potentially lead to an under/overestimation of their importance due to the unobserved effects of missing variables. Moreover, BECs change over time and space as a result of different land use and transport policies. These changes naturally affect travel behavior and, in turn, traffic safety. For example, the Netherlands underwent major developments during the 1970s and 1990s, with policies such as "Dutch New Towns" (1960-1985) and urban expansion "VINEX Areas" (1993). Safer road network designs, accessible public transport, and short distances to services (e.g., supermarkets) were some of the goals for the development of these newer areas. These spatial policies and developments together with transport planning have played a role in the declining numbers of fatal crashes [10, 14, 17] and also safer roads for cyclists. Nonetheless, these changes add to the complexity of the problem of understanding the effect of the BECs on safety because the homogeneity across different areas is lost.

[1] Based on the results of our latest accepted paper in the journal of Accident Analysis and Prevention [18].

This study developed and utilized a wide-ranging set of land-use, road network, traffic, and socioeconomic variables that affect V&B crashes in two types of property damage only (PDO) and fatality/severe injury (KSI) [18]. The spatial contiguity effects of the BECs were particularly considered in the analysis to address the spatial heterogeneities and dependencies. We compiled a rich dataset on a case study area in a selected number of municipalities in the "Randstad Area" in the Netherlands. This area is the most urbanized part of the country. The data were analyzed at 100x100 m grid cell units. We utilized Hurdle Negative Binomial (HNB) models which can handle count datasets involving an excessive number of zero outcomes (a common issue in crash count data) [19]. We also accounted for the spillover effects of some observed BECs in the neighbouring cells on V&B crashes in the target units.

Therefore, spatial HNB models were conducted to analyze traffic crashes. Figure 1 shows the "standardized coefficients" for significant variables (95% CI) of the models. Regarding the impacts of the BECs, the results show that fewer V&B crashes are likely in areas with a higher proportion of households with children. This result was expected as the speed limit of the access roads in residential areas with housing for families is set at 30km/h. Moreover, relatively many families with children live in the VINEX areas that are designed (and also found) to be safer locations for cyclists. Increased urbanization level raises the probability and frequency of V&B crashes that can be due to the higher population and the conflicts caused by an increased rate of trip attractions/generations in the areas. In contrast, a reduced crash probability was found for areas with higher land-use diversity where the locations are closer to each other. This encourages the residents to walk or cycle more. We also studied the impact of the "ages of the built-up areas" on road safety. These characteristics are used as proxy variables for various land-use policies and related land-use designs. The results suggest that areas built after 1990 are safer for cyclists in terms of occurrence of PDO crashes. These findings verify that the development of VINEX areas (in the 1990s) has had a positive impact on reducing bike involved crashes. However, our results reveal an increase in frequency of sever V&B crashes in these areas.

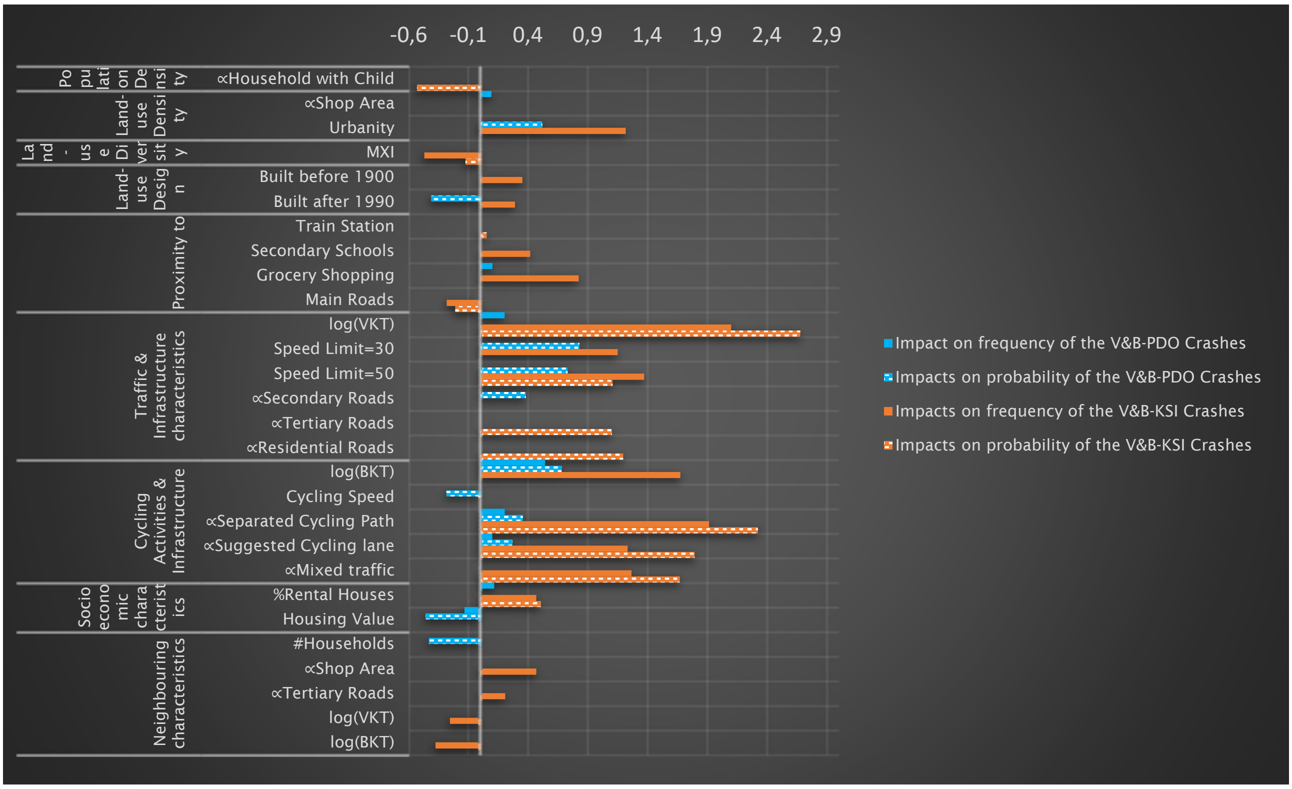

Figure 1 Comparison between the standardized Count/Zero (binary)-Model coefficients of the V&B crashes

Figure 1 also illustrates that high proximity to schools increases the frequency of severe V&B crashes. One reason for this might be the tendency of secondary school students to cycle in groups (i.e., bunch cycling). Such behavior has been found to increase the risk of sports cycling crashes in the Netherlands [20]. Also, shorter distances to schools are common in areas with older buildings which were found to be riskier areas for cyclists. Also, higher proximity to grocery stores increases the frequency and/or probability of KSI crashes in the area. Regarding the effects of the cycling facilities, the results confirm that V&B crashes are concentrated on the arterial roads that are adjacent to the high volume and high-speed roads. Moreover, separated cycle paths negatively affect the V&B crashes compared to the suggested cycle lanes and mixed traffic roads. Although the separated cycle paths prevent conflicts with motor vehicles, the presence of busy side roads, parked vehicles along the cycle paths, as well as large intersections that need to be crossed can increase the probability and frequency of V&B crashes. Finally, as for the spillover effects of neighboring variables which reflect spatial spillover effects, the results suggest that high vehicle/bicycle volumes in neighboring cells were associated with a reduction in the frequency of severe V&B crashes. Moreover, the results indicate that traffic and land-use characteristics in surrounding areas (e.g., vehicle/bicycle volumes, proportion of shopping areas) are associated with traffic safety in the targeted analysis unit.

One of the major contributions of this study is analyzing the collective impacts of a comprehensive set of BECs along with the traffic and infrastructure-related factors. This comprehensive variable set became the cornerstone to examining a cumbersome topic in cycling safety: identifying the relationship between cycling safety and the built environment. For example, this study showed that

- the magnitude of built environment impacts on safety varies based on crash severity;
- land-use density and diversity contrary affect V&B crashes in cities;
- safety of cyclists should be enhanced in areas around grocery shopping and schools;
- vehicular traffic volume is the major problem in cycling safety;
- safety of cyclists needs to be improved on territory and residential roads.

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Effect of temperature on the mechanical characteristics of bicycle tyres

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Keywords: bicycle tyre, temperature effect, test-rig, tyre characterization.

1 INTRODUCTION

Bicycles are becoming always more popular as a cheap and healthy tool for urban travels. The concerns for crowded public transport means are changing the habits after the pandemic situation caused by Covid-19, encouraging people towards the use of bicycle [1].
As stated in literature, tyres play a large role in the handling of bicycles [2] [3] [4]. This is why it is necessary to characterize tyres so as to derive useful parameters for modeling. To this purpose, proper experimental methods have been implemented for bicycle tyres [5]. A deepen knowledge of the phenomena occurring at tyre/road contact patch is indeed fundamental to ensure proper adherence and safety conditions [6], especially for vehicles as bicycles or motorcycles working with high camber angles [7].
This paper aims at enabling the future development of bicycle tyres, in order to improve the safety and the performances. Specifically, the focus is devoted to understand how the road temperature can impact on tyre performances, and therefore on bicycle handling.
After a brief section describing the methods and instruments used for this research activity, the results of an experimental campaign carried out on road racing tyre are presented and discussed.

The remarkable variation of temperature of tyre rolling surface can have multiple impacts on the performances. It can affect the noise emissions [8] as well as rolling resistance, as noted in [9], where higher temperature was correlated to lower rolling resistance coefficient. In [10] the temperature influence on car tyre lateral characteristics is investigated on a drum test-rig. A They found a decrease in cornering stiffness as temperature increases, while no particular variations on relaxation length were observed.

Despite the known influence of the temperature on tyre properties, there is a lack of studies regarding bicycle tyres. In [11] a test on test-rig of winter-type tyre revealed remarkable differences with respect to the mechanical characteristics of other tyres tested at room temperature. This may suggest the important role played by temperature on bicycle tyres characteristics, thus affecting the tyre/road interaction.

2 METHODS AND INSTRUMENTS

In this study, tests are performed with a test-rig specifically designed to measure the mechanical characteristics of a wide range of bicycle tyres [12]. Known as *Vetyt*, it consists of a welded frame made of Aluminum 6060 T6 to hold a bicycle tyre on a flat track (Figure 1). Lateral force and self-aligning moment of a road racing bicycle tyre were measured on flat track varying the temperature of the rolling surface.
Tyre was mounted on high-stiffness laboratory rim. In this way, the compliance of the rim does not affect the experimental measurements (the mounting can be seen in Figure 1).

A test with constant temperature was firstly performed (Figure 2), with camber angle set to 0° and slip angles spanning in the range ± 9.5°. The focus was devoted to the lateral force, specifically to the symmetry of the results with respect to the origin of the axes, in order to check the effective operating of *Vetyt*. The tyre should perform similarly if turned at right or left, unless the presence of secondary effects of ply-steer and conicity [13]. The temperature was kept constant at *30 ± 3 °C*. The fact that the plotted curve resulted symmetric with respect to the origin of the axis confirmed the good performances of *Vetyt*. We can assume the temperature as the only variable parameter.

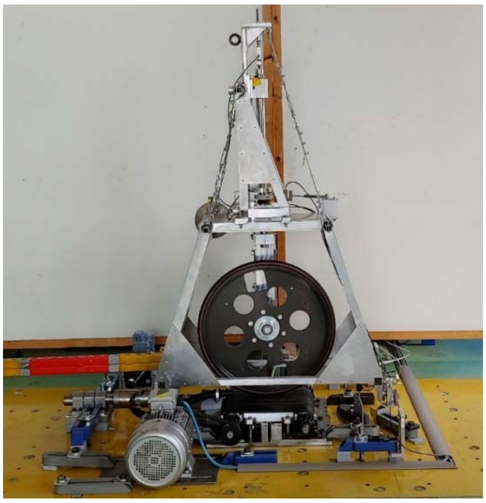

Figure 1 – *Vetyt test-rig at Politecnico di Milano. The frame holds the bicycle tyre on flat track. In this picture, tyre is mounted on high-stiffness laboratory rim.*

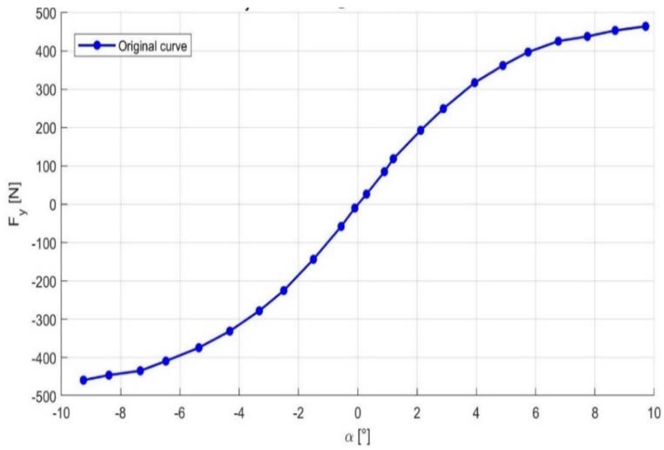

Figure 2 – *Lateral force F_y as function of the slip angle α. The result is obtained keeping the temperature of the flat track belt constant and equal to 30 ± 3 °C.*

2.1 Experimental tests varying temperature

The effect of the rolling surface temperature on the mechanical characteristics of road racing bicycle tyre was investigated. In Figure 3, lateral force and self-aligning moment are depicted as function of the recorded temperature. The slip angle was set to 3.3°. It is possible to note the remarkable correlation between the decrease of the measured values and the increase of temperature. While the temperature increases of 51%, lateral force decreases of 11% and self-aligning moment of 37%, showing an almost quadratic decreasing trend. The decreasing trend at increasing temperature is confirmed for other slip angles $|\alpha| > 3°$. Repeating the test for slip angle equal to 1°, the results are completely different, as shown in Figure 4. The variability is much smaller and limited to less than 1% for lateral force and around 8% for self-aligning moment.

Observing Figure 4, it is possible to note that values seem to achieve a maximum for temperature of 40 °C, then to decrease. This is more evident for self-aligning moment. Repeating tests for other slip angles $|\alpha| < 3°$ a clear trend cannot be distinguished, but variability remains however lower than 8% for self-aligning moment and 1-2% for lateral force.

3 CONCLUSIONS

In this article, the effect of temperature variation on mechanical characteristics of bicycle tyres is studied.
The test-rig *Vetyt*, developed in the Department of Mechanical Engineering of Politecnico di Milano, has been employed to characterize a road racing bicycle tyre. The focus was on the measurement of the lateral force F_y and self-aligning moment M_z when the temperature of rolling surface remarkably varies. The variation in temperature of rolling surface resulted as a relevant source of variability for tyre parameters. In particular, the extreme responsiveness of self-aligning moment to the temperature was noticed. While the temperature increases of 51%, passing from 31 °C to 50 °C, the measured lateral force decreases of 11% and self-aligning

moment of 37%, showing an almost quadratic decreasing trend. This result was verified for slip angle equal to 3,3°, and confirmed for slip angles larger than |3°|.

Different trend was however recorded for slip angle slip angles $|\alpha| < 3°$. Any increasing or decreasing trend cannot be distinguished, and the variability remains lower than 8% for self-aligning moment and 1-2% for lateral force.
These effects could be relevant considering paved roads during summer, when the presence of shaded corners may cause a sudden increase/decrease in road temperature, thus changing the bicycle handling. This is strictly connected to bicycle dynamics, and it could be relevant for the occurrence of sudden and dangerous dynamic instabilities [14].

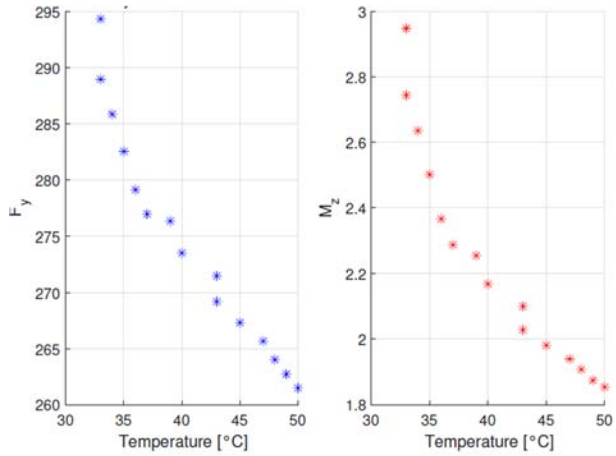

Figure 3 – *Lateral force (at left) and self-aligning moment (at right) as function of recorded temperature of belt, for slip angle equal to 3.3°.*

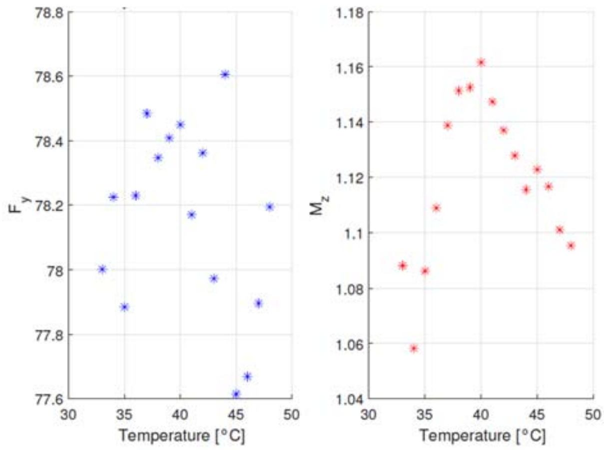

Figure 4 - *Lateral force (at left) and self-aligning moment (at right) as function of recorded temperature of flat track belt, for slip angle of 1°.*

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Urban Cycling and Automated Vehicles

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Keywords: automated driving, cycling safety, urban mobility, subjective safety, future mobility.

1 INTRODUCTION

Connected and automated vehicles (CAVs) will shape traffic patterns in the future and greatly influence urban mobility. A particular challenge for CAVs is to anticipate the movements of other road users [1]. This applies especially to micromobility vehicles (bicycles, small electric vehicles), whose traffic behaviour is difficult to predict and shaped from individual behaviour [2]. The increasing coexistence of CAVs and other, conventionally driven modes of transport thus has a growing impact as well as multiple consequences for urban structures and public space.

The following fundamental trends will shape the way people live together in cities in the coming years:

1. increasing share of CAVs and micromobility,
2. renaissance of the mixed and liveable city,
3. changes in mobility behaviour and the appreciation of public space (especially due to climate change and the Covid 19-pandemic), as well as
4. technical upgrading of infrastructure.

These parallel developments will lead to both conflicts and opportunities for cities.

2 RESEARCH PROJECT – EXAMINATIONS AND RESULTS

The research project "Concepts for the integration of cycling in future urban traffic structures with autonomous vehicles" (RAD-AUTO-NOM) investigates, how the interaction between cyclists and CAVs should be designed in urban spaces of the future. Aspects of the project include the redistribution of traffic areas and public spaces, the conflict-free design of street spaces and measures to promote environmentally friendly transport, especially cycling.

Scenarios and surveys are used to show how CAVs and the increasing share of cycling can change public space and urban structure. Furthermore, it is shown how urban and transport planning can influence future mobility. Due to partially unpredictable human behaviour, it may be difficult for CAVs to interact with cyclists, which has consequences for the drivability of CAVs in different road types of urban areas [3][4]. To facilitate the interaction of CAVs with cyclists, the overall traffic could be slowed down or a separated infrastructure for cycling could be implemented [5]. The solution of a separated infrastructure provides the opportunity to significantly increase the comfort for cyclists. The survey conducted as part of this research shows that cyclists' perception of safety is significantly higher on separated cycling infrastructure than in situations where cycling traffic is routed together with motor vehicle traffic (e.g. routing in mixed traffic or on cycle lanes). This applies especially to traffic consisting of conventional motor vehicles and CAVs which leads to a negative impact on cyclists' sense of safety.

Increasing the subjective safety of bicyclists and reducing conflicts between CAVs and cyclists by guiding them on their own infrastructure contributes to their ability to ride, but it also affects the freedom of movement in a city, especially of pedestrians, and has a negative impact on the design, aesthetics, as well as the quality of life in cities. Separating different types of traffic, especially CAVs and conventionally guided vehicles, should therefore be targeted and used sparingly, as it can hinder the further development of a mixed and vibrant city.

Slowing down traffic speed of motorized vehicles and matching their speed to slower road users on residential streets is a promising way to increase safety and driveability in all road spaces. The space for these changes towards a harmonious interaction among all traffic participants can be created in part by reducing parking areas if CAVs are used as shared vehicles. This is only possible if future traffic is organized in a way that shared vehicles, public transport and micromobility increasingly replace the use of individual motorized vehicles. The most important task for city administrations will be to limit the rebound effects of CAVs and to design public spaces, including traffic areas, in a way that cyclists, pedestrians and CAVs will coexist without conflicts. The goal should be to use the deployment of CAVs as an opportunity to design streetscapes equitably for all road users.

Equally shared streetscapes can only work if users of micromobility, especially bicyclists, feel safe and comfortable. For this reason, the research project surveyed the impacts for bicyclist's stress and uncertainty feelings to avoid them in future planning. The evaluation of the survey shows several important results due to stress and uncertainty feelings of bicyclists. Ten different bicycle infrastructures and eleven different critical situations were surveyed for three different scenarios with manually controlled and autonomous vehicles. As a conclusion, the participants did not distinguish between stress and uncertainty feelings. Both were equally stated for each infrastructure and situation in every scenario.

Motorized vehicles are found to be the main stressors for bicyclists. Riding on roads without a separated bicycle infrastructure or on bike lanes without protection from motorized vehicles, cars that fall below the safety distance or being parked on the bicycle infrastructure, dooring situations in which car doors are suddenly and unexpectedly opened, cars leaving parking spaces or property entrances and failing to notice bicyclists caused the highest uncertainty feelings of all investigated infrastructures and situations. Participants reported the lowest stress and highest feelings of safety for the scenario with CAVs only. In mixed traffic with manually controlled vehicles and CAVs, stress and feelings of insecurity seem to increase (compare figure 1).

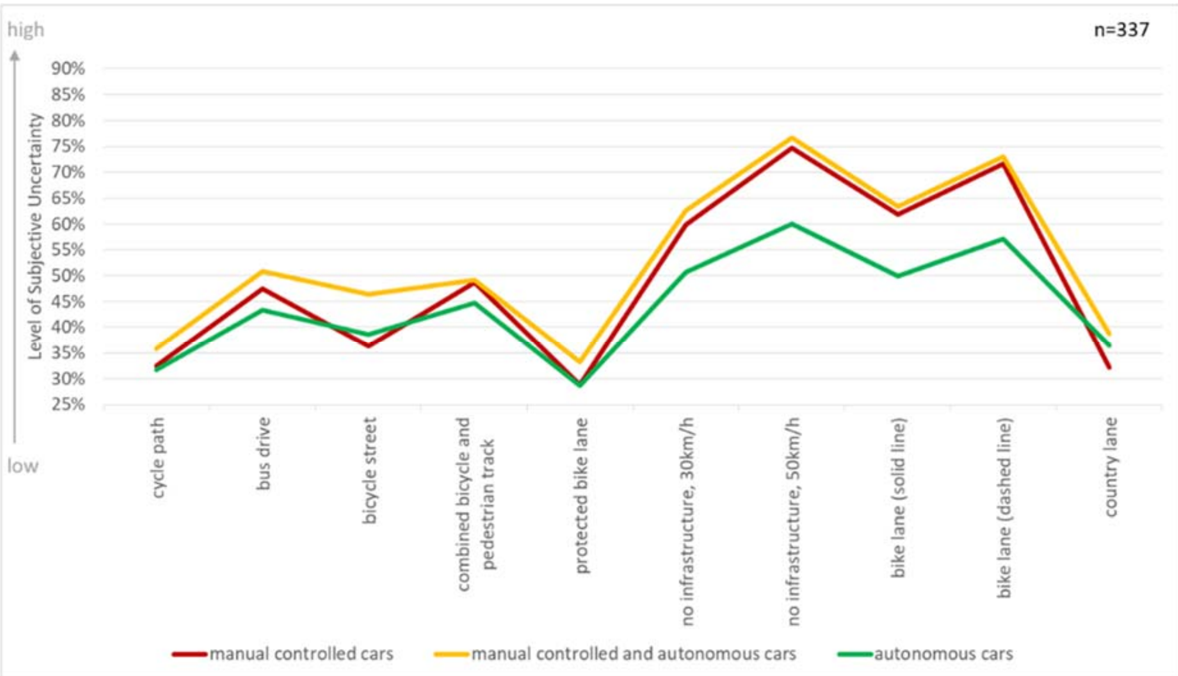

Figure 1: Comparison of the three scenarios "Manual", "Mixed traffic" and "Autonomous"

The research project has highlighted important recommendations of bicyclists for automated driving and coexistence in road space. CAVs can be expected to make huge improvements to the subjective safety of cyclists on the road. Tough, the absence of manually controlled vehicles is crucial. Initial approaches for a future urban design that combines these requirements with the technical hurdles of automated driving were also part of the research and have been summarized in a brochure.

3 CONCLUSIONS

In summary, it can be deduced from the results that it is important to fully implement the applicable regulations and guidelines regarding the safety of cyclists now. This is especially true for cycling infrastructures. Currently, there are many structures that are in poor condition, do not meet the specifications for minimum dimensions, and lack continuity (cycling network). These must be consistently adapted, on the one hand to make today's bicycle traffic more comfortable and safer, and on the other hand to make a smooth coexistence with CAVs possible. Measures that allow motorized vehicles to overtake only if the minimum distances can be maintained, as well as those that prevent the crossing of bike lanes, would have a positive impact on cycling comfort. Also, a lower speed limit, which can be ensured by a simplified designation of zones with a maximum speed of 30 km/h, would facilitate the rideability of CAVs, increase the comfort of cyclists, and contribute to a harmonized traffic flow. Additionally compact and mixed-use development is important to reduce significant commuting between people's daily destinations. The programming of CAVs and their ability to detect cyclists also ensures that the traffic regulations (StVO) are fully complied with. This can result in better and more equal interaction between all road users if intentions to act can be predicted more accurately. The design options for the traffic of the future are therefore diverse and should be used as reversibly as possible so that flexible adjustments are possible.

ACKNOWLEDGMENT

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Single bicycle accident originating from unsuccessful interactions

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Keywords: bicyclists, interactions, serious injuries, single accidents, Strada

1 BACKGROUND

In Sweden, single accidents are the biggest traffic safety problem for cyclists contributing alone with 80% of their serious injuries [1]. In this respect, the issue of bicycle infrastructure maintenance received significant attention. Slippery, uneven or in other way problematic road surface is reported as a main contributing factor in about half of the single bicycle accidents [2]. This work explores other causal mechanisms for single accidents, primarily those originating from unsuccessful interactions between cyclists and infrastructure elements as well as other objects and road users on the bicycle path.

Interactions with the infrastructure take place at locations of rapid change (often reduction) of the effective space available for cyclists. Such examples could be the narrowing of the bicycle paths at the entrance into a tunnel, speed-reducing gates, parking areas for bicycles and e-scooters, poles, manholes, tree branches and other objects hanging over the bicycle paths and forcing cyclists to adjust their travel. In such situations, the cyclist can either collide with the objects directly or lose balance as a result of the rapid speed/direction changes necessary to avoid the collision. Another risk factor is the sharp (and unexpected) turns or lateral displacements of the bicycle path itself that can be observed at the entrances to tunnels (often combined with a steep road descent) or intersections.

Collisions between cyclists and pedestrians resulting in severe injuries are relatively few, about 10% of all severe injuries [2]. It is reasonable, however, to expect that many of such unsuccessful interactions result in single falls rather than direct collisions. It was shown that about 10% of single accidents had an interaction with other road users (incl. motor vehicles) as a contributing factor [2].

2 STUDY SETUP

This complete study plan contains analysis of the bicycle single accident records in Swedish database Strada [3], analysis of cyclist trajectories at relevant location extracted using video analysis technology [4] and experimental evaluation of some of the ‘bicycle calming’ measures with the goal to find an optimal geometrical dimensions providing sufficient speed reduction of the bicyclists without compromising their stability.

In this presentation, we will report the accident analysis results.

Strada (Swedish Traffic Accident Data Acquisition) is a national database containing information about traffic injury craches [3]. The unique feature of the database is that it combines both the police crash records and healthcare records about traffic-related injuries. The first database pilot was initiated in 1999 and covered only few geographical areas. However, starting from 2016, it has nationwide coverage with all emergency hospitals reporting the injury data [5]. The police and hospital records are merged using personal identifiers of the people suffered in accidents. These identifiers are then removed and are not visible in the reports accessible to the researchers.

Bicycle single accidents are primarily known through the hospital records, having corresponding police reports available only in very few cases. It is important to note that not all patients get registered since they can choose to opt from the registration.

The emergency hospitals record the injury severity according to the Abbreviated Injury Scale[1] [6]. At the same time, the patients receive a questionnaire containing both closed-ended and open-ended questions designed to cover all types of traffic crashes. The closed-ended questions concern crash type, road state, location type and trip purpose, and the open-ended questions address the course of events before and during the accident. These accident descriptions were read and classified by the research team using a simple taxonomy developed for this study.

94,570 non-fatally injured cyclists were retrieved from the emergency hospitals' data, covering the period of 2010 to 2019. Both the open- and closed-ended questions are further analysed to select the cases relevant for the purpose of this study.

3 EXPECTED RESULTS

The expected results will present mapping of the single bicycle accidents originating from unsuccessful interactions by road state, location type, trip purpose, injury severity and injured body regions. It will also reflect which type of 'interaction' (another road user, infrastructure, obstacles, etc.) preceded the single accident.

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[1] MAIS = Maximum Abbreviated Injury, with MAIS capturing the highest (i.e. most severe) AIS code that patient sustains; AIS 1 = minor and AIS 6 = maximum.

Development of Safety Measures of Bicycle Traffic by Observation with Deep-Learning, Drive Recorder Data, Probe Bicycle with LiDAR, and Connected Simulators

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Keywords: Right-hook collisions, Drive recorder data, Probe bicycle with LiDAR, Connected simulation

1 INTRODUCTION

This research outlines the development of evaluating safety measures for bicycle traffic using state-of-the-art technology, which was started since 2020 as a four-year project. The project is funded by the Commission on Advanced Road Technology in the Ministry of Land, Infrastructure, Transport and Tourism(MLIT).

While Japan has a high bicycle modal share of 12% (2010), bicycle-related fatalities are relatively high among other countries in the IRTAD database (2019). Under these circumstances, since 2007, various measures for bicycle traffic measures have been implemented to improve the safe bicycle traffic environment, including the revision of the Road Traffic Act and the formulation of a national plan to promote bicycle use.

However, serious accidents involving bicycles are remained in some specific cases. According to the government's traffic accident analysis results (2019), right-hook crash at signalized intersections are one of the most serious types of collision involving bicycles, along with accidents at unsignalized intersections involving vehicles turning left, rear-end collisions, and single vehicle accidents due to off-road deviation. In particular, proactive safety measures are required at signalized intersections along arterial roads, where electric personal mobility vehicles traveling at speeds of up to 20 km/h are expected to share with bicycles in the future.

In order to evaluate safety measures for bicycle-vehicle crashes, this project set the following goals.

1) Identify factors influencing near-miss incidents and collisions through analysis of drive recorder data and accident statistical data.

2) Detailed analysis of traffic conditions from the cyclist's perspective using a probe bicycle equipped with a LiDAR sensor.

3) Development of an experimental environment using a connected simulator for evaluation of cooperative driving behavior.

4) Clarification of experimental conditions to evaluate different scenarios and conditions with and without intervention.

5) Proposal of effective interventions to improve crash cases based on experiments.

2 DEVELOPMENT OF TOOLS

For this project, several engineering tools to perform simulator experiments with greater accuracy were prepared.

2.1 Trajectories extracted from Faster R-CNN method

Image analysis using deep learning techniques was conducted to understand the collision situation between le ft-turning vehicles and bicycle traffic from the observed data. Using the extracted trajectory data, potential co llision risks were calculated for each bicycle traffic pattern. Crash scenarios for simulator experiments were c reated by adding the result of accident statistics data and drive recorder data of occupational drivers.

Picture 1 A Case in Kameido

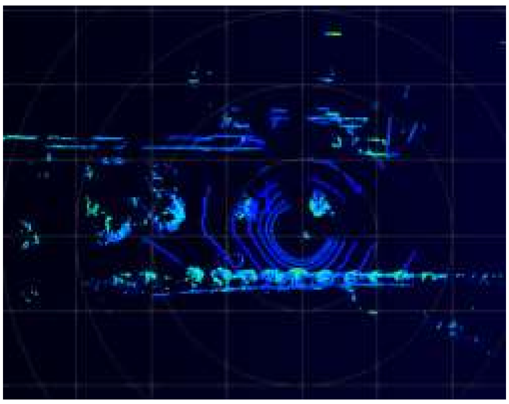
Picture 2 A Case in Oomorikita

Picture 3 A Case in Shibuya

2.2 Probe bicycle with the LiDAR sensors

A probe bicycle is a bicycle equipped with a GPS unit, video cameras, and the Velodyne Lidar VLP-16. the Lidar outputs three-dimensional point data that can reveal the shape and relative position of surrounding vehicles and other objects within 100 meters. By using this bicycle to collect data in actual conditions, it is possible to understand the requirements for inter-vehicle communication to prevent collisions. It can also be used to verify the accuracy of experiments in virtual space by obtaining data such as trajectories and relative distances from the actual road environment and comparing the data on the simulator.

Picture 4 Prove bicycle.



Picture 5 Example data from Lidar on Bicycle.

2.3 Connected simulator system

Two types of simulators were prepared for virtual experiments. The first one is a 180-degree cylindrical screen type with an additional rearview monitor, side mirror monitors, and a rear side window that can be projected by a projector. The second one is a head-mounted display that provides a 360-degree field of view. Driving simulator and cycling simulator are connected in the system allowing the user to freely drive each in the same virtual space, as well as generate other computer-operated vehicles. These simulator systems can be used for evaluation tests of cooperative behavior between subjects in situations where collisions are expected. An example of a virtual road space is to vary the corner components of a protected intersection to evaluate what combination of conditions is a reasonable measure of ensuring safety.

Picture 6 Connected Simulator system with screen type.

Picture 7 Connected Simulator system with HMD type.

3 CONCLUSIONS

This paper provides an overview of the study and its component tools. Each progress result for this project will be shared at the conference.

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The relationships between accessibility and crash risk from social equity perspectives: A case study at the Rotterdam-The Hague metropolitan region

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Keywords: job accessibility, gravity model, cycling safety, trip purpose, social equity.

EXTENDED ABSTRACT

Traffic safety and accessibility have been two important subjects in transportation research. On the one hand traffic crashes bring about high societal costs and serious health risks for urban road users. The cost of traffic crashes is estimated to be 17 billion euros per year only in the Netherlands while over 600 people were killed in traffic, of whom 229 were cyclists and 195 were car users [1, 2]. Accessibility, on the other hand, is regarded as one of the indicators of the quality of the transport system serving the public. There is comprehensive literature investigating the relationship between traffic crashes and factors associated with traffic, roadway design, built environment, and human factors. Similarly, several studies assessed and evaluated accessibility levels of individuals, communities, and regions by utilizing the aforementioned factors. Nevertheless, there is a scarcity of literature investigating the relationships between accessibility and traffic safety. This is especially surprising considering that both subjects are associated with a similar set of factors, including land use and transport systems, as well as individual and temporal factors [3-7]. The relationships between accessibility and traffic safety can be an adverse one; for example, improved accessibility by increasing the travel speeds (i.e., declining travel time) intensifies the crash risks which also deteriorates equity. Furthermore, levels of both accessibility and traffic safety are not homogeneous throughout urban areas and among different population groups. Based on the literature, it is obvious that accessibility is associated with economic equity [8]. It is revealed that accessibility of lower-income groups is substantially worse than the higher-income groups as these groups have less mobility [9]. Previous studies also showed that lower-income groups usually suffer from traffic safety problems more than other socio-economic groups [10-12]. Therefore, this research aims to address the aforementioned gap in the literature in understanding the relationships between accessibility levels and traffic safety with a focus on social equity perspectives. For this purpose, a Gravity model and risk exposure evaluation approaches are utilized to analyze traffic safety and accessibility to jobs by bicycle via extending the traditional definition of accessibility based on only travel time or proximity to a location.

This study aimed to find the relationship between job accessibility and crash risk, using a case study on work travels by bikes in the Rotterdam – The Hague metropolitan region. By use of GIS software, potential job accessibility was estimated for each postcode-4 (PC-4) zone using a Gravity model that incorporates the travel time between origin and destination and the number of jobs at the destination. The crash risk estimation was done based on actual bicycle-involved crash data for the period 2015-2019. The EPDO values were calculated on the routes and the crash risks on cyclists are expressed in the monetary crash risk per origin per person per year.

This research uses a three-step analysis approach including crash risk estimation, job accessibility analysis, and statistical analysis. First, the shortest path routes for cycling trips to jobs are identified by using travel time. Then, safety risk per route for the identified shortest paths was calculated by weighting the crashes based on the costs associated with their severity levels and the exposure of cyclists through the routes (i.e., € per bicycle-kilometer-traveled). The accessibility levels are calculated by the Gravity model and safety risks are calculated by using the aggregated risks per route for analysis units in the study region. Consequently, multiple

linear regression modeling approaches are utilized to model the relationships between accessibility, safety, land use characteristics, and socio-demographic factors. The results of two multiple regression models indicate contradictory impacts of some land use and socioeconomic factors on traffic crash risk and job accessibility which are two important factors in transportation analyses.

Figure 1 shows potential job accessibility in each PC-4 area within the study region. The potential accessibility level indicates the level of opportunities, here the total number of jobs, that can be reached from a PC-4 area which is reduced as the distance between the areas increase. In this figure, a quantile classification interval is used because of the distribution of the data, resulting in ranges with unequal sizes but a better presentation of the results. Unsurprisingly, the highest job accessibility values are in the more urban areas and cities of Rotterdam and The Hague. The lowest accessibility values can be found in the southwest. Next, as it is shown in figure 2, the total crash cost per inhabitant per origin PC-4 zone per year is calculated. This figure reveals that different from the potential job accessibility levels there is no clear pattern in the monetary value of crash risk on cyclists.

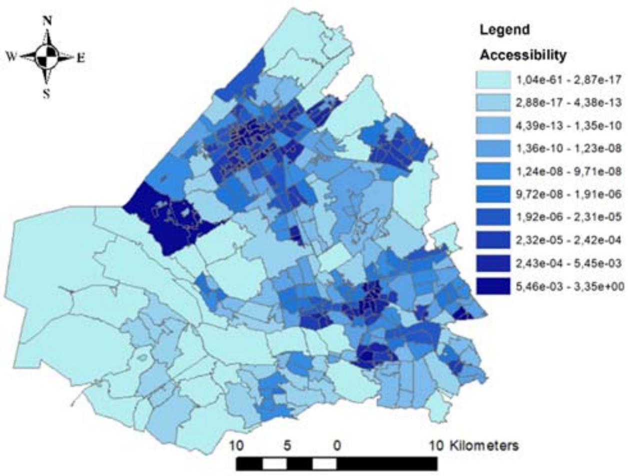

Figure 1 Potential accessibility level

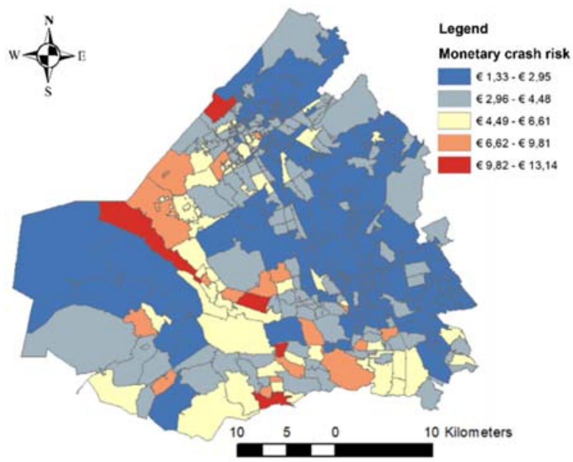

Figure 2 Monetary crash risk per inhabitant per origin

The relationships between job accessibility and crash risk were analyzed by conducting two multiple linear regression models by controlling for independent variables, including population density, income level, age-group populations, density of different types of bicycle infrastructure as well as land use features. The crash risk model showed that cyclists are at more crash risk in areas with lower income levels. Moreover, a higher population aged between 15 and 44 years old predicts a lower crash risk in the PC-4 areas.

To compare the impacts of the independent variables on both job accessibility and crash risk we compared the magnitude of the coefficients of a similar set of land use and socioeconomic variables in both models. To make the coefficients comparable they are transformed into standardized coefficients. Figure 3 shows that the impact of the different age groups is much higher on crash risk than on job accessibility level. This can be explained by known strong relation between crash risk and the age of travelers [13]. Furthermore, it stands out that for population density and income level the direction of the estimated coefficients in the crash risk model are negative, whilst they are positive in the job accessibility model. Meaning that higher population density and income levels in the areas are associated with lower crash risk and higher job accessibility. Also, a higher ratio of living, facilities, and industrial land uses is correlated with increased crash risk and reduced job accessibility in an area. Similar to the previous studies (e.g., Chen and Shen [14]) we found developing high mixed land use areas helps to enhance cyclists' safety, however, our results show a decreased job accessibility in these areas. Job accessibility and cycling safety, on the other hand, are both positively affected by increased population density. These findings suggest the decision-makers for further investigations on tradeoffs between improving safety and enhancing accessibility.

The results of this comparative analysis indicate that the low-income people are not only less advantaged in terms of job accessibility, but also exposed to a high level of crash risks. In addition, compared to other age groups, the population group aged between 45 and 64 are at higher crash risks, and also their accessibility to jobs is lower than other the other age groups. These findings become rather more beneficial for the decision-makers, considering the probable mutual impacts of land-use and transport developments and projects (i.e., improved accessibility) on safety of different population groups.

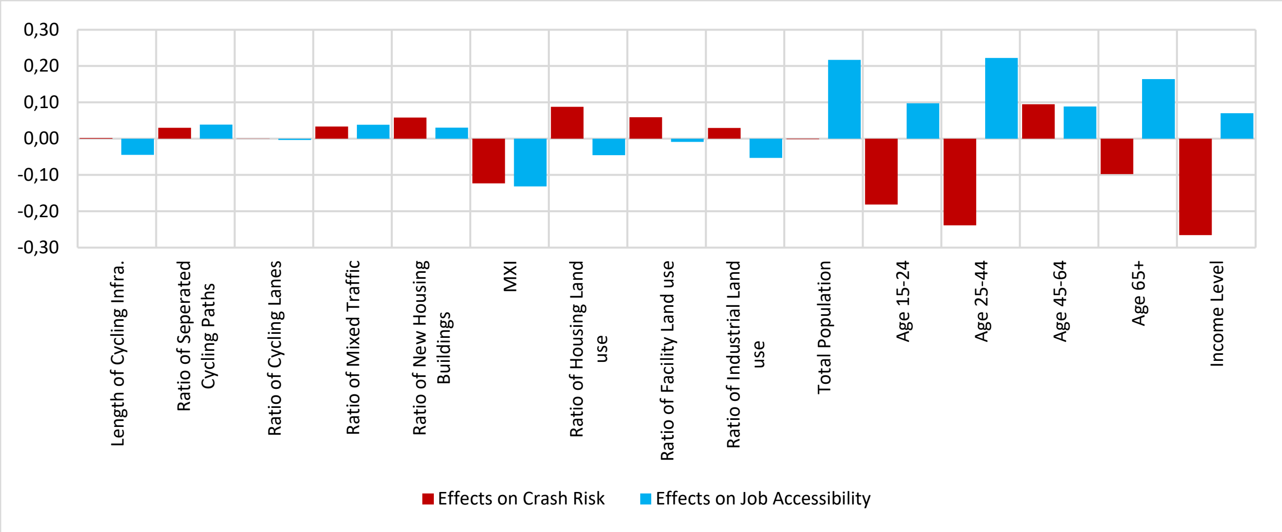

Figure 3 Standardized regression coefficients for two models

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Cyclist support systems for future automated traffic: A review

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Keywords: cyclists, bicycles, human-machine interface, support system, automated vehicles

1 INTRODUCTION

Interpreting the subtleness and complexity of vulnerable road user (VRU) behaviour is still a significant challenge for automated vehicles (AVs). Solutions for facilitating safe and acceptable interactions in future automated traffic include equipping AVs and VRUs with human-machine interfaces (HMIs), such as awareness and notification systems, and connecting road users to a network of AVs and infrastructure. The research on these solutions, however, primarily focuses on pedestrians. There is no overview of the type of systems or solutions supporting cyclists in future automated traffic.

The objective of the present study is to synthesise current literature and provide an overview of the state-of-the-art support systems available to cyclists. The aim is to identify, classify, and count the types of communicative technologies, systems, and devices capable of supporting the safety of cyclists in automated traffic. The overall goal is to understand AV-cyclist interaction better, pinpoint knowledge gaps in current literature, and develop strategies for optimising safe and pleasant cycling in future traffic environments with AVs.

2 METHODS

We collected data through literature searches and then taxonomically coded and analysed the identified concepts. To collect relevant academic articles, we performed literature searches in the databases Scopus and Google Scholar. In addition, we used Google to identify informal concepts from the industry. The criterium for selecting the study sample was set to transport-related concepts capable of transferring messages or information among road users through technology, where articles not involving cyclists or bicycles were excluded. In total, we identified 62 publications that fit the inclusion criteria: 38 journal or conference papers, 18 commercial or industry products, four patents, one book section, and one poster. Several of the publications contained descriptions of more than one system, adding up to the identification of 92 concepts in total.

The study sample was analysed systematically using a taxonomical coding system: sorting, categorising, and counting the concepts across 13 dimensions based on terminology, the number of interfaces and placement, modality and strategy of communication, the systems' functionality, and the method of evaluation of the concepts. The results from the coding system were analysed through descriptive frequencies and pivot tables.

3 RESULTS

The descriptive analysis of the coding and categorisation of the 92 communicative concepts showed that one out of three concepts was categorised as having more than one placement, see Figure 1. The most common placement of the system or interface was cyclist wearables (39 % of all concepts), closely followed by on-bike devices (38% of all concepts), and vehicle systems (33% of all concepts). About one in four concepts had placements on infrastructure or projections on infrastructure.

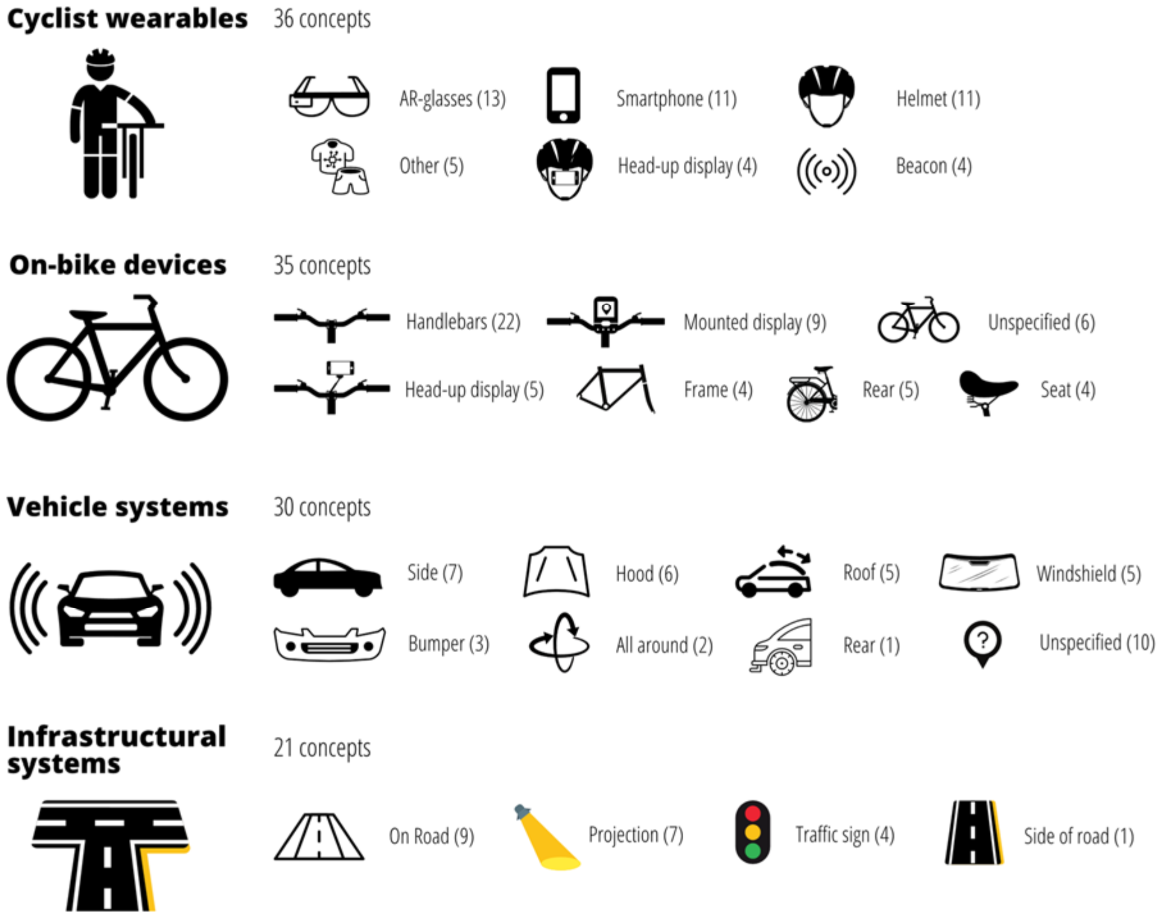

Figure 1: HMI placement of the 92 concepts.

The most common communication modality was visual; four out of five concepts communicated their message visually. Abstract/light was the most frequent modality (54% of visual concepts). For visual interfaces, red (19%), green (18%), and yellow (13%) were the most recurrent colours.

Approximately one out of three concepts used auditory and motion-based communication modalities. The most common way of auditory communication was a signal or buzzer (17 concepts, 68% of auditory concepts), typically as an alert or warning to the cyclist. In about two out of three motion-based concepts, the modality of communication was haptic feedback, like vibrating handlebars. Nine concepts use gestures, typically to control augmented reality (AR) glasses. 38 out of 92 (41%) concepts involved a connectivity feature or technology with the potential of connecting multiple agents to transmit messages.

The concepts were categorised with functionality spanning three groups of systems: information systems, warning systems, and support systems. Two-thirds of the concepts functioned as information systems, informing the user about a particular arrangement or sequence of events. However, the most common functionality across concepts was a warning system communicating an alert of an imminent or potential conflict or collision. Only 11 of the concepts were coded as a support system, conveying messages with a behavioural component of the cyclist or bicycle, such as information about a cyclist's current or potential future behaviour.

4 DISCUSSION

Cyclists differ from pedestrians in terms of eye-gazing behaviour, speed, and movement patterns; while pedestrians usually interact with vehicles at crossings, cyclists regularly share the road and travel parallel with vehicles, experiencing crossing, merging, and overtaking situations. Almost all of the concepts categorised as vehicle systems (97%, 29 out of 30 concepts) had the functionality of an information system. Most of these concepts were external on-vehicle HMIs (eHMIs) targeting pedestrians and cyclists, and only seven concepts were omnidirectional (i.e., with placements on the roof or all around the vehicle). The differences between VRUs must be considered in the design and evaluation process of eHMIs. It is essential that the interfaces are visible from all around the vehicle to accommodate the differences in movement patterns and that the message can be observed at the higher speeds of cyclists.

When anticipating their needs in future automated traffic, interviewed cyclists' main concerns were visibility and confirmation of detection by the automated vehicle [1]. The concepts identified in our study have the potential to cover these needs. For instance, CommDisk, a 360° rooftop-mounted eHMI providing omnidirectional two-way communication [2], and The Tracker, a band of light surrounding the vehicle illuminating a small segment in the spatial proximity of the detected VRU [3], both show potential to accommodate the topography and needs of cyclists.

Moreover, several concepts categorised as cyclist wearables and on-bike devices were warning systems detecting a nearby entity, using targeted communication to alert the cyclist of a potential conflict. Most of the vehicle system concepts aimed to inform the cyclist of the vehicle's current or future behaviour by broadcasting messages. Combining these concepts by utilising the bandwidth mode of communication by connecting the cyclist or bicycle to a network of AVs and infrastructure might enhance visibility and provide sufficient acknowledgement to the cyclists. Such vehicle-to-everything concepts exist; however, the complexity of implementation and use is a major future challenge.

5 CONCLUSION

The findings from this study provide a synthesis of the present literature on AV-cyclist interaction and an overview of the state-of-the-art cyclist support systems. In the final paper, we aim to further align this overview with knowledge about cyclists and their behaviour from a human factors perspective, assess whether the solutions meet cyclists' needs, and explore their potential impact on cyclists in the future.

Concluding on a recommended system based on the identified concepts is challenging as most concepts have not been tested nor evaluated with automated vehicles, and the results are ambiguous regarding the need and necessity of the systems in future traffic. However, the overview we provide is helpful for future research, testing, and development of concepts for supporting cyclists in future automated traffic.

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Evaluating cycling programs for 10- to 14-year-old children

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Keywords: cycling safety, children, secondary school, standardization, evaluation.

1 INTRODUCTION

Children between the age of 10 to 14 increasingly use their bike as a means of transport. Unfortunately, they still show deficits in competencies needed for safe traffic participation (e.g. erratic attention or self-awareness). This is reflected in an increase in the risk of accidents involving bicylces for 10- to 14-year-olds: 56.8% of 10- to 14-year-old children who have had road traffic accidents in 2020, had bicycle accidents [1].

In Germany, there are various programs to improve bicycle safety for children. In contrast to the „Fahrradführerschein“ (bicycle driving license which usually takes place in fourth grade), programs for 10 to 14 year-olds are less standardized and various offers exist. There has been no evaluation on the quality of these programs yet.

Therefore, we developed an evaluation standard for programs that aim to improve cycling safety for 10- to 14-year-olds. To do so, a catalogue of criteria was developed which helps describe and evaluate cycling projects for children in this age group. We then evaluated existing projects and collected them in a web-based database. Our aim is to provide a guideline to evaluating cycling safety programs for 10- to 14-year-olds and to offer an overview about various existing programs.

2 CRITERIA CATALOGUE USED TO DESCRIBE AND EVALUATE CYCLING PROGRAMS

First, we developed a criteria catalogue to describe and evaluate current programs. For this, we conducted a literature search on developmental aspects of children's cycling abilities and on the design of learning and instruction programs [2]. We also obtained data from police accident statistics and analysed them with regard to age-specific accident characteristics. In total, 9.003 accidents involving cyclists between the age of 10 and 14 were analysed. The literature review and the accident data analysis were used to derive criteria for cycling safety programs targeted at 10- to 14-year-olds. We discussed this preliminary criteria catalogue with four experts in the field of road safety education and adjusted it based on their comments.

The resulting criteria catalogue consists of two main parts. The first part consists of criteria to describe projects (e.g. type of program or description of target group). Criteria in this part can only be answered in a dichotomous manner (criteria met vs. not met). The second part consists of criteria used to describe the extent to which certain quality criteria are met (e.g. evaluation of media design or general concept). Criteria in this evaluative part are answered on a four-point scale (very true, somewhat true, rather not true, not true at all). The final criteria catalogue is four pages long and consists of 15 criteria which 2 to 8 items each. Table 1 gives an overview about the lists of criteria used.

Table 1: Overview about structure of criteria catalogue used to describe and evaluate cycling safety programs for 10- to 14-year-olds

	Criteria	**Number of items**
Description of program	Description of topic	4
	Description of target group and addressees	4
	Content about: safety, social, health and/or environmental education	6
	Type of program material	6
	Accessibility and implementation	8
	Inclusion of age-specific accident characteristics	6
Evaluation of program	Inclusion of cycling competencies	7
	Concept	3
	Understandability for target group and addressees	2
	Empowerment to act	2
	Content design	5
	Media design	4
	Practicability	2
	Transfer	4
	Quality assurance	3

Next, we then used the criteria catalogue to describe and evaluate existing programs. For this, 10 programs aimed at improving cycling safety of 10- to 14-year-olds were identified via web searches. Programs contents were analyzed and for each the different criteria were filled in. This pilot study enabled us to test the feasibility of the catalogue. We concluded that it is best when each program is evaluated by at least two experts who read and analyze the material. This is due to a high variety of programs and ensures a common understanding about the programs' contents.

3 RESULT: THE DATABASE AND DESCRIPTION OF USE CASE

The criteria catalogue was implemented to a web-based database. The database was developed at Fraunhofer IVI Dresden. It serves as a storage for the cycling safety programs and their respective evaluations. This means that for each program in the database, items of describing and evaluating criteria are stored and can be retrieved.

In the future, we aim to make this database publicly available. Interested stakeholders, practitioners and researchers can use it to research cycling programs for 10- to 14-year olds. Figure 1 shows a first draft of the user interface. Users can select their desired criteria (e.g. type of program or duration) via a search template. The database then provides a list of matching programs, including further information on the sources of the programs.

The following use case would be possible: Many traffic safety programs aim to take place in a school setting, since many students between the ages of 10 to 14 come to school by bicycle. However, there is no standardized, predefined way for implementation, so implementation heavily relies on teacher engagement. A teacher could therefore look for a short program with the duration of one teaching unit and does not require additional material. The teacher can use the database to search for programs that meet these requirements by indicating his/her preferences using the search template. The resulting lists of programs provides the teacher with an overview about possible programs he/she could implement.

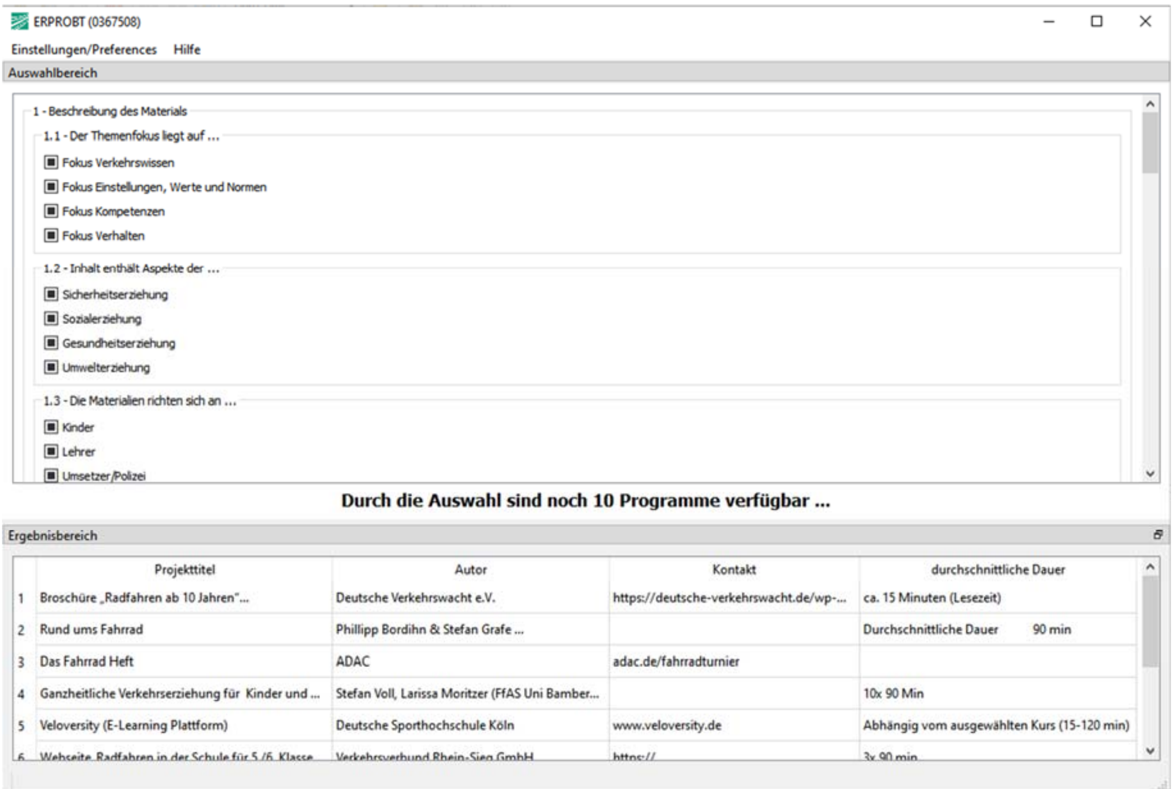

Figure 1: Screenshot of database. Upper part ("Auswahlbereich") shows search template and lower part ("Ergebnisbereich") shows resulting list of matching programs.

4 OUTLOOK

The criteria catalogue and the corresponding database offer an important tool in collecting, describing and evaluating cycling safety programs for 10- to 14-year olds. At the moment, the database contains about 40 programs. More programs will be added in the future. Additionally, we will use the database for the following two goals.

4.1 Identification of gaps in programs

The collection of programs in form of the database allows to analyze and compare programs regarding their content. In this way, missing content can be identified. As part of our pilot study including 10 programs, it became evident that many projects did non focus on age-specific accident characteristics. For example, none of the 10 projects addressed the danger of distraction using smartphones or headphones. It should be noted that these are still preliminary results and analysis of additional projects are pending. The identification of gaps enables further development of programs and provides direction for future research.

4.2 Evaluation of database by users

The search template is a central aspect of the database as it helps users find their desired programs. We are therefore planning to evaluate the usability of this search template with various stakeholders (e.g. teachers, parents, practitioners). Depending on the type of user, different criteria are of interest. A teacher or a parent, for example, might be more interested in facts regarding the feasibility of programs and therefore use criteria that describe simple facts about the programs. A researcher or a traffic safety practitioner, on the other hand, might be more interested in the evaluation of programs and thus use criteria that describe the quality of programs. The results of these usability tests will be used to further adjust the search template.

5 CONCLUSIONS

Children are prone to cycling accidents between the age of 10 to 14. There are numerous programs targeting cycling safety exist of this age group. Our work has two objectives: one is to develop a standardization tool in form of a criteria catalogue to describe and evaluate these programs. The other is to provide an overview about these programs in form of a web-based database. The database can be used by practitioners to search for suitable programs (e.g. teachers looking for a program to implement during the lessons or parents looking for brief information to provide to their child). It also serves to identify gaps in current programs to enable further development and provides direction for further research.

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Reported changes in cycling habits among older adults during the early months of the COVID-19 pandemic, New South Wales, Australia

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Keywords: cycling, older adults, participation, COVIC-19.

1 INTRODUCTION

The impact of the 2020 COVID-19 pandemic and the associated public health measures enacted by governments globally had a significant impact on all aspects of human life including economic activity and mobility. One of the main public health measures designed to reduce the transmission of the SAR-CoV-2 virus have been the implementation of various levels of lockdowns that limited mobility and resulted in almost half of the world's population under some form of confinement [1]. Many governments, including in Australia, UK, and Norway, enacted flexible forms of lockdowns that allowed daily outdoor exercise, while adhering to safe physical distancing, in recognition of the role of physical activity in reducing the mental and physical consequences of confinement [2]. Australia saw first strict lockdown restrictions over March/April 2020 with progressive easing of restrictions during May and June 2020.

Emerging evidence from these countries has indicated that physical activity, particularly cycling, increased over the lockdown period and the following months as some restrictions were eased [3,4]. However, many have warned of a decline in physical activity with serious health consequences among older adults who were at a higher risk of morbidity and fatality associated with COVID-19 and were more likely to be confined to their homes for longer periods compared to younger age groups [5].

The aim of this study was to investigate the impact of COVID-19 pandemic on cycling activity among older adults aged 50 years and over in New South Wales (NSW), Australia during the early months of the COVID-19 pandemic.

2 METHODS

The cross-sectional survey is part of a larger study that investigated cycling safety and mobility in older people [6]. Older adults were recruited through various cycling and seniors' community organizations to complete an online survey during a two-month period between May and June 2020 which saw a progressive easing of restrictions imposed over March/April. Participants were included if they met the following criteria: aged 50 years and older, resident of New South Wales (NSW), and had cycled at least once during the previous 12 months.

3 RESULTS

Of the 1335 respondents, 53% reported a change in recreational cycling during the study period. More participants (34%) reported riding more for recreation purposes during the pandemic than riding less (18%) with a difference +16% (Table 1). However, this difference decreased with age with the highest reported by cyclists aged 50-64 (+17%) and the lowest by 80+ (-13%) with more reporting that they rode less during the study period (33%) than riding more (20%). Significantly more females reported cycling more for recreational purposes during the pandemic than males with net gains of 23% and 14% respectively. Increases in riding for recreational purposes during the study period were higher in unemployed participants (40%) compared to employed participants (19%). Regular riders (ride at least 3 days/week) were significantly more likely to report an increase in recreational cycling during the study period (net gain of 16%) compared to occasional cyclists (ride less than once a week) where more reported riding less for recreational purposes (Table 1).

The majority of participants reported no change in riding for commuting purposes (75%). More respondents reported riding less for commuting purposes (18%) compared to those who reported riding more (7%). Younger groups aged 50-64 were significantly more likely to report less riding for commuting compared to older cyclists. The same was observed for regular cyclists compared to occasional cyclists (Table 1).

Most respondents (61%) found riding during the pandemic to be safer than previously compared to only 8% who found it to be less safe. This proportion was higher in males (63%) compared to females (58%) and regular cyclists (64%) compared to occasional cyclists (48%).

Table 1: Changes in cycling activity in older adults and perception of safety during the COVID-19 pandemic by demographic and riding frequency.

	Recreational cycling			**Commuter cycling**			**Safety Perceptions**		
	Ride more	Ride less	Difference	Ride more	Ride less	Difference	Safer	Less safe	Difference
Age									
50-64	36.3%	18.91%	17.39%	8.59%	22.39%	-13.8%	62.83%	7.61%	55.22%
65-79	30.65%	16.58%	14.07%	3.02%	6.53%	-3.51%	58.04%	8.79%	49.25%
80+	20.0%	33.33%	-13.33%	13.33%	13.33%	0	53.33%	0%	53.33%
P value	0.04			<.001			0.26		
Gender									
Males	32.35%	18.56%	13.79%	6.09%	18.26%	-12.17%	62.47%	6.39%	56.08%
Females	40.35%	17.87%	22.48%	9.51%	15.85%	-6.34%	58.21%	11.53%	46.68%
P value	0.02			0.07			<.001		
Employment									
Employed	36.86	18.0%	18.86%	9.49%	24.82%	-15.33%	63.26%	6.08%	57.18%
Unemployed	52.08	12.5%	39.58%	NA	NA	NA	64.58%	14.58%	50%
Retired	28.08	19.44%	8.64%	NA	NA	NA	57.24%	10.37%	46.87
P value	<.001						0.009		
Frequency of riding per week									
Less than once	28.99%	33.33%	-4.34%	2.9%	8.7%	-5.8%	47.83%	10.14%	37.69%
1-2 days	33.33%	21.79%	11.54%	5.13%	10.9%	-5.77%	54.81%	11.54%	43.27%
At least 3 days	35.15	16.05%	19.1%	7.87%	20.36%	-12.49%	64.32%	6.51%	57.81%
P value	<.001			<.001			<.001		
Total	34.38%	18.35%	16.03%	6.97%	17.6%	-10.63%	61.3%	7.9%	53.4%

4 DISCUSSION AND CONCLUSIONS

Nearly double the number of participants aged 50 years and over reported riding more for recreation purposes during the early months of the pandemic compared to riding less. This might be due to a combination of factors, including low traffic volumes and interim improvements to public space such as narrowing roads, closing lanes, as well as rolling out temporary cycleways implemented in NSW during the pandemic which is likely to have increased perceived safety among cyclists. Most respondents found riding during the pandemic to be safer than previously.

Significantly more women increased their recreational cycling than men. This might be due to anecdotal evidence of increasing number of women taking their children going on rides with during the pandemic but might also be related to women being more sensitive to issues about safety, inadequate cycling infrastructure and interaction with other motorists than males.

This overall observed improvement in recreational cycling during the early months of the pandemic declined with age with those aged 80+ reporting an actual decrease in activity. This calls for public health programs to support those in this age group to maintain a healthy level of physical activity, particularly in the face of pandemic-related restrictions.

More respondents reported riding less for commuting purposes compared to those who reported riding more. While the survey period (May -June 2020) saw easing of restrictions imposed earlier in March in the state of NSW, people were still encouraged to work from home which is likely to be behind the decline in cycling for commuting purposes.

The pandemic offers an opportunity to reshape urban environments and build adequate cycling infrastructure that supports safe cycling as part of COVID recovery efforts.

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E-Scooters appear on bike infrastructure: users and usage, conflicts and coexistence with cycling

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Keywords: micromobility, e-scooter, vulnerable road user, safety, urban mobility.

1 INTRODUCTION

E-scooters are a rather new mode of transport [1]. Nevertheless, in recent years lots of studies have been published. Replaced modes and consequential environmental impacts [2, 3] as well as specific injury pattern [4, 5] are important topics. Regarding shape, speed and usage, e-scooters are most similar to bikes. As a consequence, by law e-scooters use the same road space or infrastructure than bikes do. Concurrently, in recent years we experience a boom of cycling in cities [6] and a significant expansion of the bike infrastructure [7]. Requirements and frequency of usage on the bike infrastructure are growing in cities caused by increasingly diverse cyclists [8]. At the same time, the bike infrastructure is subject new requirements and additional pressure due to the implementation of e-scooters. In Germany, allowing e-scooters on bike infrastructure can be seen as a paradigm shift since for the first time a motorized vehicle is allowed to use the infrastructure.

On this background, interrelation between e-scooters and active mobility (walking and cycling) are very important for the future use of the infrastructure and the ongoing transformation of urban mobility. Hence, we use a multi-method approach to investigate these potential conflicts and draw conclusions for regulation as well as improvement in the system.

2 METHODS

The multi-method approach contains three methodological components: First, we conduct an online-survey for users and non-users to evaluate usage behavior, motives and opinions as well as experienced conflicts within the system of active mobility [9]. Second, we analyze data of shared fleets to identify movement patterns and hotspots [10]. Third, we perform expert interviews to assess the appraisal of stakeholders involved.

A Germany-wide online survey on the topic of e-scooters in road traffic was conducted in spring 2021. E-scooter users and non-users participated. Participants were recruited via social media, newsletters, disseminators, and a cooperation with an operator of e-scooter sharing. The questionnaire covers a wide range of questions on e-scooter usage, including trip purposes, combination with public transport, and reasons of use. Furthermore, opinions on e-scooters in cities as well as experienced conflicts between e-scooter users, pedestrians and cyclists were provided by both, users and non-users. A total of 3,834 persons participated in the survey, of which 1,226 were e-scooter users. On that basis, we investigate motives to choose the e-scooter over other modes of transport.

The trip data is based on repeated API-requests of e-scooter locations every two minutes for a timeframe of roughly one year in 2020 and 2021 in the city of Berlin, Germany. The data of each API-request includes, among others, geographic positions, vehicle identifiers and timestamps. By using this combination, start and end locations of vehicle movements can be identified. The derived date allows for spatiotemporal analyses of usage and identify according hotspots. In addition, information on substituted mode of transport derived from the online survey allows to estimate emission balance.

Stakeholders, such as city representatives, researchers and operators of shared e-scooters in several German and European cities are interviewed. We aim to collect their assessment on the topics supply, utilization, regulation as well as conflicts and safety. Thus, we aim to and trace different regulations and experiences in European case study cities.

3 RESULTS

Results of the online survey show that e-scooter users are rather young, male, employed and have a high education. Regarding trip purposes, compared with the representative German mobility study MiD [11], the share of trips with shared e-scooters to work and leisure activities corresponds approximately to the average of all modes in the MiD, while trips for private errands are much more frequent. With private e-scooters, share of trips for shopping and private errands match well with MiD data for all modes, whereas trips to work are far exceeded. The trip purpose 'just for fun' was not gathered in MiD survey.

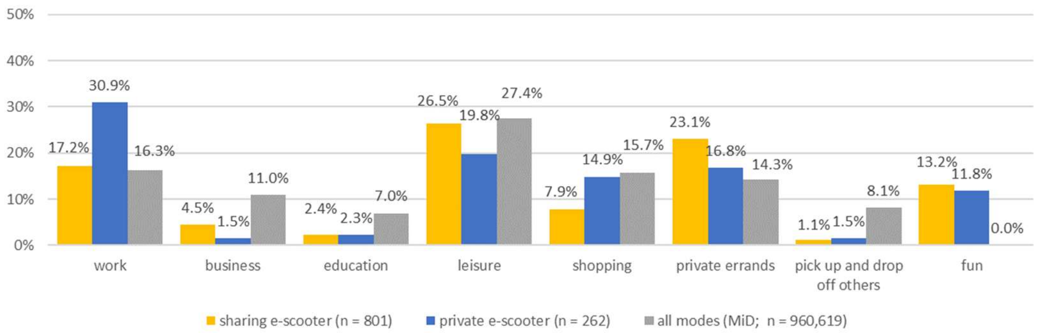

Figure 1. Trip purposes on the last trip with a sharing or private e-scooter and distribution of trip purposes in Germany from the MiD 2017. Source: own data, 2021, and [11].

Almost 90 percent of the participants already experienced conflicts between e-scooters and active modes and specified information regarding the type of the conflict, location, parties involved, and reason for the conflict. Thereby, most conflicts are experienced as pedestrian while 57.2 percent of cyclists specified at least one conflict. Figure 2 gives an overview about the type of conflicts experienced by pedestrians and cyclists. The fullpaper and the oral contribution will include comprehensive information about the information specified (type of conflict, location, parties involved, reason for conflict).

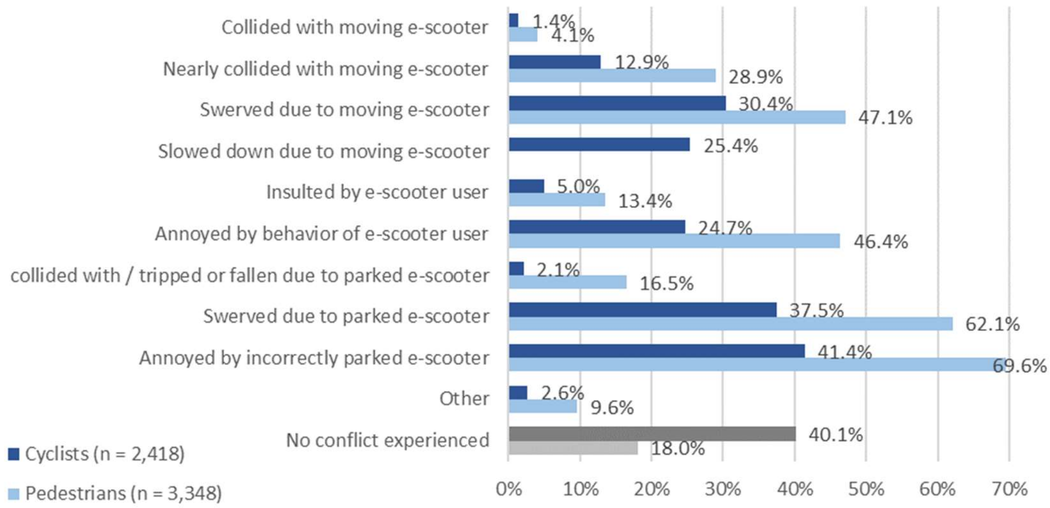

Figure 2. Experienced conflicts as pedestrian and cyclist

The analyses of trip data reveal the spatial distribution of e-scooters in the city of Berlin. Also, we evaluate temporal differences. These analyses allow to identify areas of special importance for the conflicts of interest for further research.

Expert interviews allow to widen the perspective and include the assessment of stakeholders involved. Similar to users in the online poll, the experts see parked e-scooters as bigger problem than moving e-scooters. In addition, improper using behavior is stated to cause problems. While the regulatory frameworks de facto differs between the case study cities, most experts agree on desired regulation measures. These refer to general organization of the service in terms of special use permissions or concessions as well as measures like automated speed reductions, zoning and integration into public transport.

4 CONCLUSIONS

This contribution provides insight into the particularities of E-scooters as a new mode of transport. We deliver comprehensive information on the state of knowledge regarding e-scooters from different perspectives. In addition, we investigate the interrelations between bicycles and e-scooters as traditional and new users of the bike infrastructure using mixed methods. The main findings of the research are: The utilization is divers and shared e-scooters are used differently than privately owned. The potential for conflicts is large. Thereby problems caused by parked e-scooters are much bigger than those caused by driving e-scooters. Further reaching regulation is desired by most stakeholders.

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The influence of an active steering assistance system on the cyclist's experience in low-speed riding tasks

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Keywords: Pedelec, safety, field study, balance, stability.

1 ABSTRACT

At low speeds, older cyclists have a higher risk of losing balance and having an accident on a pedelec than younger cyclists. A stability assistance system with an electric motor acting on the handlebars can provide steering assistance and help stabilize a pedelec. However, the steering interventions can possibly affect the cyclist and his riding experience. Using a steer assisted pedelec, this study investigates the influence of these interventions on the cyclist and his riding experience at low speeds.

30 men and 30 women between 59 and 84 years of age participated in a field test. Each participant completed two riding tasks using an instrumented pedelec with a steering assistance. The participants had to ride at low speeds (5 km/h and 6 km/h) and complete a cycling course with five riding tasks that require low speeds. The riding tasks were repeated alternately with an activated and deactivated assistance system. Participants were not told whether the system was activated or not. After each ride, the participants compared the current ride with the previous one using a Likert scale with 5 items (2=much better, 1=slightly better, 0=no difference, -1=slightly worse, -2=much worse). Stability was evaluated by recording several stability-related measures during the rides.

The measurement results show that the steering assistance system provides significant stability improvement, yet 43 % rated these rides as slightly to much worse, 28 % as slightly to much better and 29 % saw now difference.

Three factors were found that explain the cyclists' ratings: The assistance system and the cyclist interact with each other via the handlebar; this is unfamiliar to the cyclist and the benefit is not directly recognizable (I). The assistance system compensates for a lack of stabilization skills or ineffective steering interventions by the cyclist through countermovement, that gives the cyclist the feeling of losing control (II). The subjective loss of control, which in this case affects a safety-critical component of the pedelec (the handlebar), consequently reduces the cyclist's sense of safety (III).

These results indicate that a steering assistance system is not immediately seen as beneficial by the cyclists. To increase the acceptance, training courses could be offered that allow cyclists to get used to the system over a longer period. To counteract the feeling of losing control, the system's intervention should be as minimal as possible.

Highlight Statements

- Evaluation of a steer assisted pedelec while riding at low speeds.
- A controlled electric motor providing steering assistance can improve stability.
- 60 cyclists compared their riding experience with and without steering assistance.
- Most cyclist perceives the steering assistance as unfamiliar and not beneficial.
- Steering interventions help with stabilization, but can be felt as counterproductive.

Are Pedelec crashes different to bicycle crashes? A comparison of national accident data in Germany

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Keywords: Pedelec, bicycle, comparison, crash data, Germany

1 RESEARCH QUESTION AND OBJECTIVE

Since 2014, a distinction between Pedelec (electrical support up to 25 km/h) and bicycle crashes is made in official police reported accidents with personal injuries in Germany. Yet, no comparative analysis using national data is available, moreover some estimation was done how Pedelec crashes may look like based on bicycle crashes [1]. Hence, the present study aims to compare real-world crashes with personal injuries with both vehicle types – Pedelec and bicycle and show similarities and differences of the vehicle classes. Nearly a decade of reporting allows furthermore to have a closer look at the accident figures in a time series and to estimate possible trends.

2 DATA SOURCES AND METHODS

Accidents involving personal injury are recorded by the authorities in Germany. Once an accident happen the police will be notified and starts to collect crash data using an official report. Important parameters are collected by the police at the scene of the accident and then transmitted to the federal statistics authority (DESTATIS) via the state statistics authority. The data used in the study were provided by the statistics authority via special evaluations, as they are not freely accessible to the extent required. The information is requested at annual intervals. In the study, the processed accident statistics were analyzed comparatively for the years 2014 - 2020 according to various characteristics such as accident situation, collision opponents, locations, injury severity or rider age for cyclists and Pedelec riders [2]. In addition, the accident figures were set in relation to other important parameters (e.g., stock, mileage) to better compare the accident risk against other road user types [3, 4]. The final analysis of the time series provides insights into the trends regarding the accident occurrence of conventional bicycles and Pedelecs in future and enables further targeted measures to improve road safety.

3 RESULTS

The number of accidents with personal injuries was visibly declining until 2010/11. For some years now, a stagnation or slight increase in the number of accidents has been observed [5]. This stagnation can be observed till the Covid 19 pandemic in 2020/2021. Lockdowns, curfews, and home offices have led to a significantly different traffic pattern. Fewer vehicles on the roads therefore also lead to fewer conflicts and thus, fortunately, to fewer accidents on the roads. On the other hand, this led to an increase of Pedelec and bicycle usage during this time.

3.1 Number of registered cycling accidents (including Pedelec) in Germany

The trend regarding accidents involving cyclists has been increasing for more than 10 years (+20% compared to 2004). It should be noted that the number of accidents involving cyclist fatalities has continued to fall since 2004. In relation to the year 2004, there is a reduction of -11% in fatal cycling accidents. An important characteristic is the accident type. The accident type describes the traffic situation (conflict situation) that led to an accident. A comparison of the accident incidents between bicycle and Pedelec accidents shows only one significant difference for the year 2020. The share of riding accidents (accidents with loss of vehicle control) is significantly higher for Pedelecs (26%) than for conventional bicycles (19%). When looking at the time series, it can be seen for conventional bicycles that the absolute accident figures for intersection and turning conflicts have fallen significantly in recent years, which is essentially due to an improvement in the infrastructure and introduction of vehicle safety systems in car and commercial vehicle segment. However, the significant increase in accidents with loss of vehicle control in the last 5 years is remarkable. Similar trends are found in the absolute accident figures for Pedelecs if the annual increase figures are also considered. The increase in all accident categories can still be largely explained by the significant increase in Pedelecs in the field (sales figures).

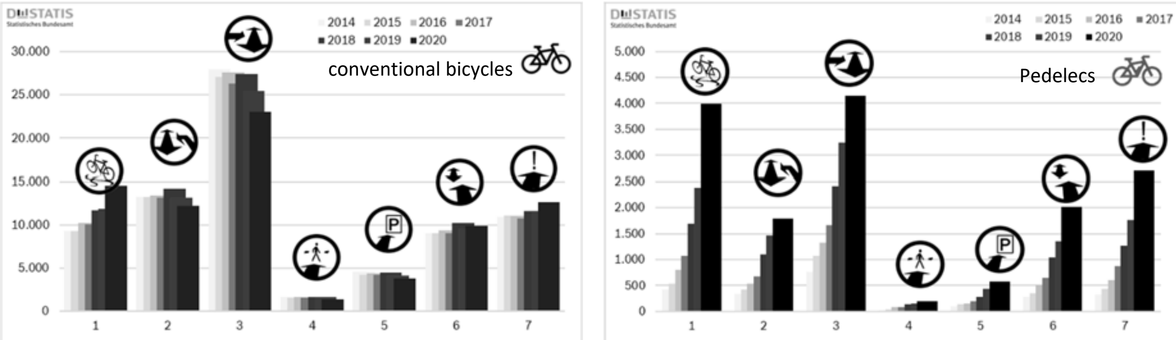

Figure 1: Accident type, Accidents with conventional bicycles (left), accidents with pedelecs (right)

3.2 Further accident characteristics

The official accident statistics provide information on other important accident characteristics. Thus, the type of accident opponents, type of collisions or other characteristics can be taken. The known accident characteristics can also be considered in relation to accident severity or location. The age of the accident victims is shown here as an example. Users of conventional bicycles in accidents with casualties have a significantly lower average age than Pedelec users. Around 49% of cyclists involved in accidents have an age of <40 years. The proportion of this age group among Pedelec riders involved in accidents is just 19% for 2020. The often-higher age of Pedelec riders involved in accidents therefore has a very clear influence on the resulting injury severity. This results in a higher proportion of serious injuries and fatalities among Pedelec users than among conventional cyclists.

3.3 Linking accident figures with other parameters

Since the spread of Pedelecs on the roads will increase significantly, the trend in accident figures is also very variable. Specially to enable a comparison with bicycles, it makes sense to relate the accident figures to other parameters, e.g., inhabitants or registered vehicles. Since bicycles and Pedelecs do not have to be registered in road traffic, it is not possible to draw direct conclusions about the size of the vehicle fleet in the field. Considering an average use of 7 years, it is possible to determine the fleet size in the field based on the annual sales figures. Figure 4 clearly shows how the stock of conventional bicycles has been continuously decreasing over the last few years and is being replaced by Pedelecs. Furthermore, a trend reversal in the total stock (bicycles + Pedelecs) can be observed from 2015 onwards. However, the increase is only due to the growing popularity of Pedelecs. It can be assumed that in the coming years, conventional bicycles will continue to be "replaced" by Pedelecs and that additional new user groups will be developed for Pedelecs (e.g., leasing Pedelecs, Cargo Pedelecs, etc.).

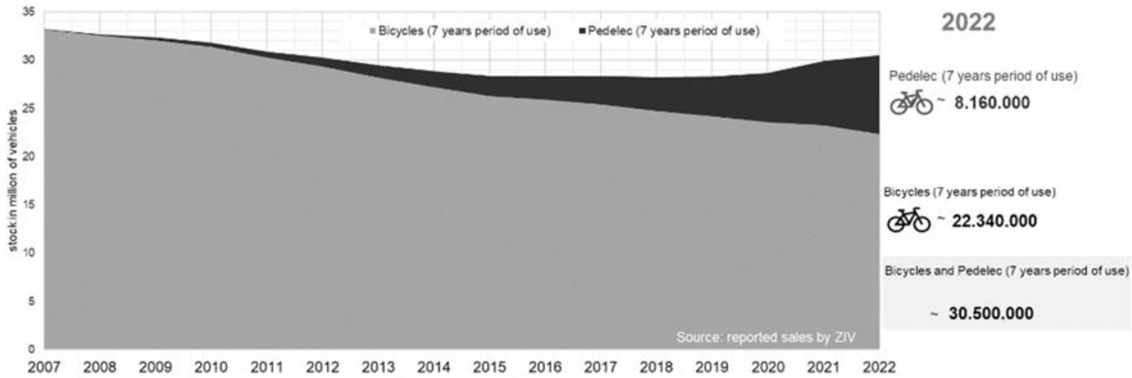

Figure 2: Vehicle stock according to pedelec/bicycle sales figures for 7 years of use

However, when looking at accidents in relation to 100 000 vehicles in the field, a different picture emerges. There are significantly fewer accidents with personal injury per 100 000 vehicles for Pedelecs than for conventional bicycles. This is remarkable, because the average mileage is not included in this analysis (significantly higher for Pedelecs). The increase in Pedelecs in recent years can be explained, among other things, by changing usage behavior (e.g., more frequent use as a commuter vehicle, etc.). The regular rate of use is determined at 7 years according to the depreciation table for fixed assets [6] of the Federal Ministry of Finance. This value is also assumed for Pedelecs. This results in the following parameters:

Table 1: Accidents regarding stock. [3,7]

Road user type	Accidents with casualties 2020	Vehicle stock	Accidents per 100 000 vehicles	Source stock
pedelec	15 415	6 640 000	232	sales (7years)
conv. bicycles	77 537	23 260 000	333	sales (7years)
motorcycle	25 120	4 570 318	550	registered
car	195 099	47 017 269	415	registered

The distance travelled also plays a very important role when considering the frequency of accidents, as a vehicle that travels significantly longer distances can also have more accidents as a result. Observations show that Pedelecs are used for significantly longer distances due to the electric assistance. There are now various data from studies on average mileage. The Federal Ministry for Transport and digital infrastructure gives an annual average value of 439 km/year for conventional bicycles [8]. Various studies show significantly higher mileages for Pedelecs. Mileages between 1 000 km/year and over 2 000 km/year are given. Considering the average mileage, the expected number of accidents with personal injury per billion kilometers travelled is higher by a factor of about 3 for cyclists than for Pedelec users (Pedelec: 2 322 vs. conv. bicycles: 6 667 accidents per billion km).

4 LIMITATIONS AND DISCUSSION

The use of official crash statistics provides a representative and meaningful insight to the accident situation in Germany, as the data contain every accident with personal injuries recorded by the police. Limitations in the coverage are only to be expected for single bicycle or Pedelec crashes, as well as collisions with slight and minor injuries or property damage crashes only, as these are not notified and reported to the police.

5 CONCLUSIONS

The present study shows that the accident situation of Pedelecs is rather similar compared to the accident figures involving bicycles. Age of users and single vehicle crashes are the main differences observed in national data which is often mentioned in the media. However, still some increasing trend is expected as a change in the mobility sector currently in ongoing and cycling becomes more popular also for commuting. As some of the cyclists will replace their bicycle with a Pedelec some compensation will occur and in long-term some decreasing trend for bicycle crashes is estimated. This again must be observed using national crash data.

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Challenges to implementing cyclist counting systems on rural roads

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Keywords: cyclist detection technologies, sport cyclists, cycle volume, rural road.

1 INTRODUCTION

In Spain, the presence of sport and recreational cyclists on rural roads has increased notably in recent years. In fact, the number of federation licences reached 75,638 cyclists and 3,634 cycling clubs in 2020 [1]. As the number of cyclists on these roads has increased, so has the number of accidents. Despite regulations, information campaigns and measures taken by the Spanish Directorate-General for Traffic in recent years, the number of crashes involving cyclists in rural environments remains plateaued at near 50 cyclist fatalities per year [2].

Most Spanish rural roads do not have specific infrastructure for cyclists – e.g. cycle lanes. Then, cyclists and drivers share the road and interact; being the overtaking manoeuvre one of the most dangerous interactions. These interactions imply risk of rear-end and side-on collisions with cyclists and head-on collisions with oncoming vehicles during the overtaking manoeuvre. Since traffic crashes and risk exposure are highly correlated, every interaction between cyclists and/or with motorised vehicles increases the likelihood of a traffic crash. Consequently, to properly assess road safety on rural roads, an adequate estimation of cycle volume is needed.

On the other hand, cyclists may ride in groups in different configurations (in-line or two-abreast), which can also affect the traffic operation by creating queues and increasing the delay time of motorised vehicles [3]. Therefore, determining the volume of cyclists on a rural road segment is a necessary challenge in order to integrate them into safety and traffic operation analyses.

Cycle volume is of great interest for many applications. In fact, knowing the spatial and temporal distribution of cycle volume across a road network can help engineers to plan and manage these roads, improving road safety and traffic operation.

Furthermore, knowing cycle volume can also help motorised drivers. Warning drivers about the presence of cyclists before reaching them improves road safety, as drivers can adapt their behaviour to interact with cyclists more safely. One tool to inform drivers of the presence of cyclists in this environment is the use of vertical signs. These systems have evolved in recent years, from simple static signs (informing of the possible presence of cyclists), to the implementation of active and intelligent signs. Active or dynamic signs alert drivers about the presence of cyclists in real time, raising their level of attention. This is extremely important, since driver inattention or speeding was present in half of crashes involving cyclists on Spanish rural roads.

There are many technologies for cyclist detection. Most of them have been used in urban areas, where cyclists have specific facilities. However, rural roads present particularities due to the type of infrastructure, users, and how they interact. For this reason, the main objective of this study is to analyse what challenges existing counting systems must overcome in order to be effective on rural environment. The analysis will consider the particular characteristics of the phenomenon to be detected, both the characteristics of the cyclists themselves and of the road.

2 METHODOLOGY

The methodology to be followed is shown in Figure 1. As a preliminary step to the characterization of the counting systems, it will be necessary to analyse the phenomenon.

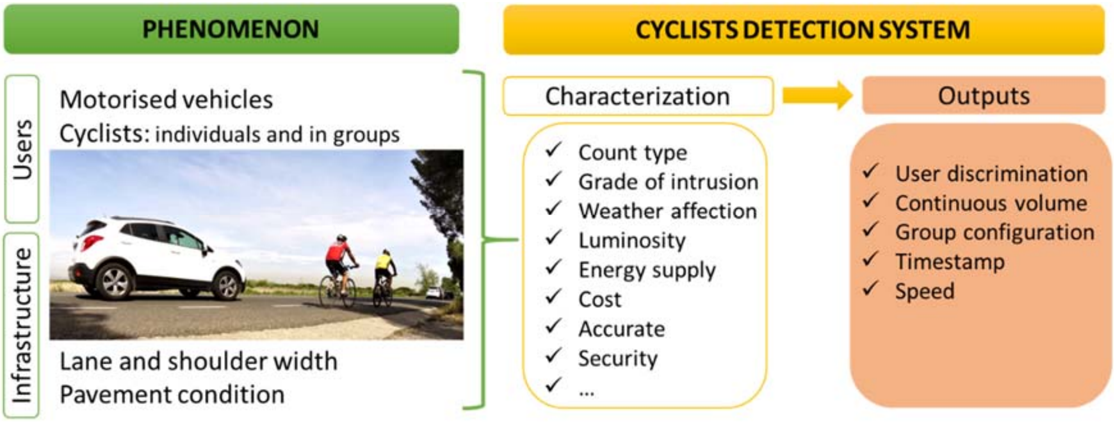

Figure 1: Workflow.

Characterization of the phenomenon: In Spain, motor vehicles and cyclists can share rural roads. Spanish Regulations allow cyclist groups to ride in line, and if there is enough sight distance, they can ride at maximum two-abreast. Cyclists must ride along the shoulder or, if not possible due to its width or maintenance level, along the right side of the lane. The overtaking manoeuvre is also regulated, requiring a minimum lateral distance of 1.5 m. To facilitate traffic operation, overtaking bicycles even with a solid line is allowed [4].

Cyclists detection system: It is necessary to characterize the detection and counting technologies to identify the specific constraints that limit their use in relation to the analysed phenomenon. The main limitations are related to the way in which they count (continuous or discontinuous): the degree of intrusion on the infrastructure (taking into account the speed reached by motorized vehicles on rural roads); the environmental impact, ensuring a detection resistant to weather and not affected by luminosity. In addition, in an interurban environment, a counting system must be sufficiently autonomous and not require continuous maintenance. The risk of vandalism must also be taken into account. Taking into account the particularities of each counting system analysed as well as their combination, the most interesting technology will be the one that can provide the results shown in the Figure 1. These variables are of great interest for the efficient and secure management of the infrastructure.

3 RESULTS

A total of 29 scientific articles and more than 16 websites related to detection and counting systems applied to transport have been reviewed. From the analysed data, Table 1 has been composed, showing the main analysed technologies for detecting and counting cyclists on two-lane rural roads considering their main advantages and limitations (to be implemented in these environments).

Some of these technologies have already been used to detect road users on urban environment (cyclists and/or pedestrians), such as 2D LiDAR or magnetic loops, with good results. However, it is necessary to validate them for accurate estimation of cycle volume on rural roads, especially regarding when cyclists ride in groups.

The detection and counting system has to discriminate cyclists from other road users. This will be achieved by incorporating an algorithm that allows this discrimination to be made by processing the information captured by the sensors. A potential tool for discrimination is the Artificial Intelligence through machine learning techniques; which allows the system to feed back the input data, recognise a cyclist and count him/her.

Table 1: Detection and counting technologies analysed with their main advantages and limitations.

Technology	Advantages		Limitations	
RFID devices	Economic Individual information	Permanent counting Groups of cyclists	Low penetration rate	
Pneumatic tubes	Economic	Easy installation	Temporal counting Intrusive	Uncomfortable and unsafe
Piezometric sensors	Permanent counting	Not affected by weather	Intrusive Non-covered areas	Groups of cyclists occlusion
Magnetic loops	Permanent counting	Not affected by weather	Intrusive Non-covered areas	Specific for carbon fibre
RADAR sensors	Permanent counting Not affected by weather	Non-intrusive Speed registration	High cost	Groups of cyclists occlusion
Thermic sensors	Permanent counting Low luminosity	Non-intrusive	Extreme weather	Complex Hardware
LiDAR scanners	Permanent counting Low luminosity	Non-intrusive Speed registration	High cost	Complex Hardware
Visible HD cameras	Non-intrusive	Image support Speed registration	High cost Privacity	Needs luminosity Complex Hardware

4 CONCLUSIONS

Due to the continuous increase in the number of sport cyclists on two-lane rural roads, combined with the stagnation of crashes involving cyclists and the affection on traffic operation, it is necessary to analyse and implement new measures to improve safety and traffic operation on these roads. Knowing the volume of cyclists on these roads allows a more realistic and efficient planning of countermeasures.

The first step in designing and implementing a real-time detection and counting system for cyclists on roads is a review of existing technologies for detecting and counting cyclists. These counting systems also provide information on the temporal distribution of the volume of cyclists on a road. Detection and counting systems have to overcome the specific limitations related to the environment and the characteristics of the road users. A counting system must to be continuous, and must discriminate cyclists from the rest of road users. Another requirement is to detect all cyclists when riding in a group.

Several detection and counting systems have been analysed, listing their advantages and disadvantages for use in the detection of cyclists on rural roads. The use Artificial Intelligence algorithms improves the discrimination of cyclists in these conditions. The possibility of combining different of the mentioned systems and tools has also been considered, giving rise to a complex system. From this review, the best systems are selected and taken to phase two, where they will be field-tested for validation.

ACKNOWLEDGEMENTS

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Cyclist-Pedestrian Cohabitation in Seasonal Pedestrian Streets

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Keywords: Bicycling, safe cycling, active transportation, road safety, video analysis, pedestrians, surrogate measures of safety.

1 INTRODUCTION

There is a renewed focus on active modes of transportation given their multiple advantages, whether for human health or the environment in general. Interest has grown especially in 2020 after the COVID-19 pandemic, when several cities quickly implemented temporary facilities for walking and cycling in the context of physical distancing. Several measures piggybacked on existing programs such as the Montreal initiative for complete streets ("rues conviviales" or "social/festive streets") that selects streets each year for pilot projects and a final design implementation over a three-year period. This resulted in seasonal pedestrianization of about ten streets each year since 2020. Though active transportation brings together pedestrians and cyclists under a large umbrella, these users have very different characteristics and there may be conflicts of use if mixed in the same space. Cycling is thus generally forbidden on pedestrian streets. Despite these rules, there is cycling traffic on pedestrian streets as cyclists also enjoy car-free facilities, especially when pedestrian traffic is low, which generates complaints by pedestrians. To reconcile and help both categories of users coexist, two Montreal boroughs tried a new rule in the Summer of 2021, to let cyclists bike at walking speed on pedestrian streets while avoiding conflicts with pedestrians. There are few studies on cyclist-pedestrian interactions [1] [2], and, to the best of the authors' knowledge, none on interactions in pedestrian streets.

This work aims to study the coexistence or cohabitation of pedestrians and cyclists in several pedestrian streets through video-based analysis. Data were collected at several sites and on several days during the Summer of 2021 along three different pedestrian streets, two of them allowing cycling, to assess how cyclists and pedestrians interact, whether cycling is allowed or not.

2 METHODOLOGY

This study relies on the direct observation of pedestrians and cyclists. This is done by collecting video data for several days from a camera attached to poles like lamp posts. The video data is then semi-automatically analyzed using computer vision methods (from the open-source Traffic Intelligence project). This starts with camera calibration, to project the positions of the video image users to real positions. Road users' trajectories are then extracted, classified (between pedestrians and cyclists) and manually verified to obtain the road user trajectories. The pedestrian-cyclist cohabitation is analyzed through two categories of indicators:

1. traffic indicators for each cyclist: speed and acceleration; and
2. safety-related indicators about the interactions of cyclists with pedestrians.

The second category relies on surrogate measures of safety [3], which have been applied to cyclists using video data [4] and GNSS data [5]. Interactions occur when a pedestrian and a cyclist are close enough in space and time. The distance, time-to-collision (TTC), and cyclist speed near a pedestrian are computed for each interaction.

3 PRELIMINARY RESULTS

This paper reports on a preliminary analysis made for 20 to 30 min in the morning for each site. Four indicators are shown in Figure 1 for eight sites in three streets: cycling is allowed on the first two, Mont-Royal and Wellington, while it is forbidden on the third, Bernard.

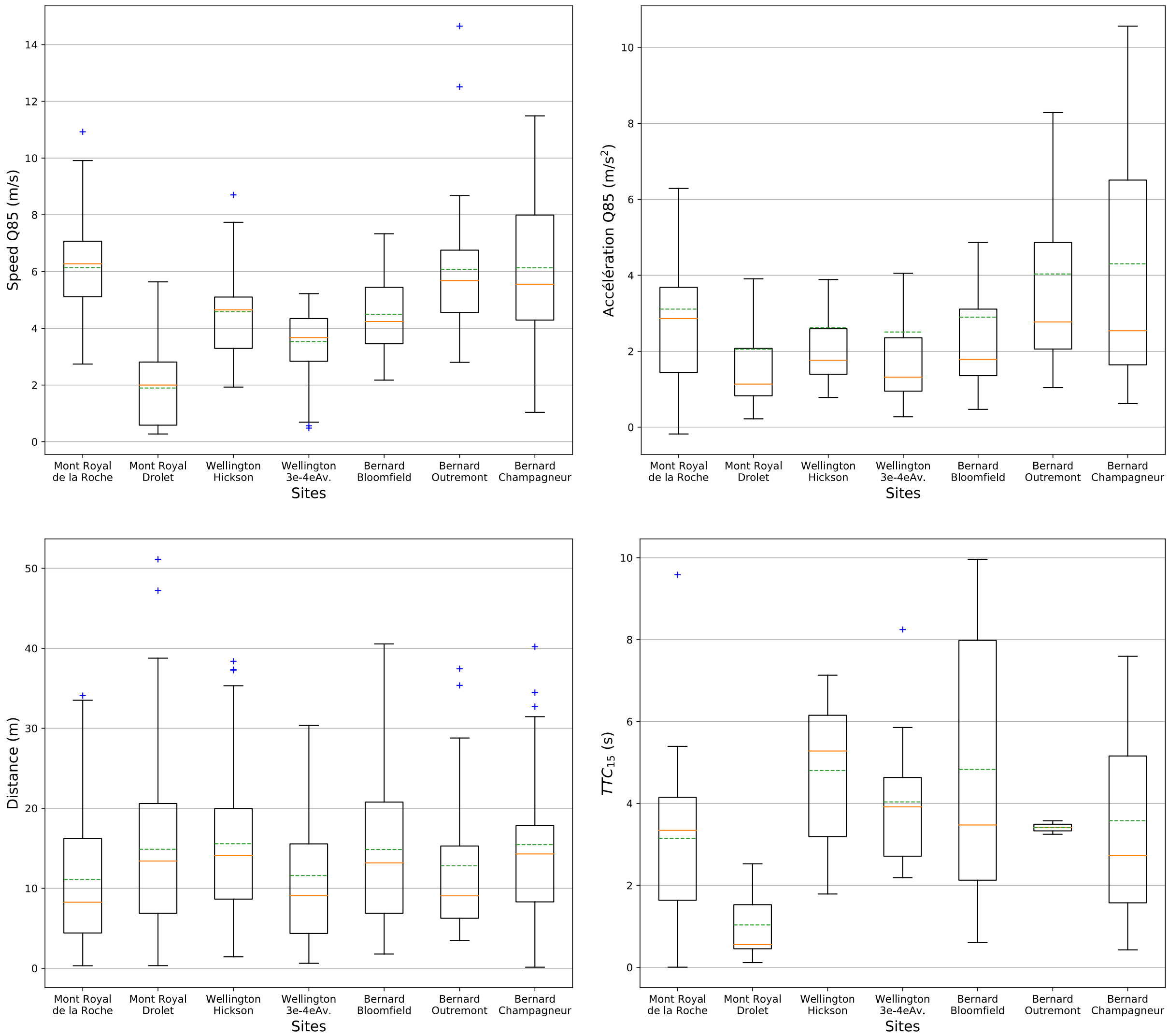

Figure 1 Boxplot of the 85th centiles of the speed (top left) and acceleration (top right) of each cyclist, distance (bottom left) and TTC_{15} (bottom right) of each cyclist-pedestrian interaction per site

The speeds vary between the different sites, but not according to the rule for cycling. Some values are unexpected: the lowest speeds were recorded on the site where the slope is the steepest, i.e., Mont-Royal and Drolet, and the highest values also on Mont-Royal, at the De La Roche site. Thus, other factors could explain the observed speeds: for example, the width of the street has become narrower (and "feels" narrower) at Drolet due to the addition of terraces and urban furniture, which encourages cyclists to reduce their speed, especially in the presence of other users. Regarding accelerations only the 85th percentile is presented here as it corresponds to the maximum accelerations: it shows the lowest values on Wellington, a disparity in value between the two sites on Mont-Royal, similar to speed, and the highest values on the Bernard sites. Despite the data cleaning, the accelerations remain very high and are probably overestimated.

When looking at cyclist-pedestrian interactions, their distances (minimum value) seem adequate for all sites. The speeds of cyclists near pedestrians are not shown in the plots for lack of space and because the results are similar to the other speed data. As for the TTC values, the 15th percentiles (minimum values) shown in Figure 1 (bottom right) are generally high (more than 2 s) for most sites. Only the Mont-Royal and Drolet site presents relatively low values compared to the other sites, which seems surprising considering the other indicators, which requires more detailed analyses.

4 CONCLUSION

The conclusion of these preliminary results is that cyclist-pedestrian interactions seem to be safe, regardless of the rules about cycling in pedestrian streets. These results will be confirmed on the analysis of the whole dataset (two or three days of data for each of the eight sites) and the behaviour of cyclists will be characterized according to other factors such as the width of the street, its organization and pedestrian density.

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Attention allocation and subjective risk at un-signaled intersections – A virtual cycling game

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Keywords: Attention allocation, subjective risk, intersections, virtual environment.

1 INTRODUCTION

The probability of a cycling crash is much higher at intersections as along the road (e.g. [1], [2]). A number of reasons contribute to this difference, for example car drivers overlooking cyclists when taking a turn. There have been attempts to quantify the risk at prototypical, un-signaled intersections featuring different levels of cycling infrastructure (e.g. [3]), as well as cyclists' perception of risk of these intersections [4]. However, these attempts are limited to regular, four-arm intersections, although irregular intersections featuring both a higher and a lower number of arms as well as odd angles are likely to pose additional challenges for cyclists. There appears to be little research on the question how the complexity and layout of such intersection affects cyclists' perception of risk, as well as their allocation of attention towards the different arms of an intersection. In [5], we presented a first approach to tackle this issue in a virtual reality (VR) based setup. We found evidence that the type of turn affected the subjective risk (e.g. with a higher risk associated with situations requiring a sharp turn or to continue to an offset road), but no effects of the general position of an intersection arm in relation to the cyclist' traveling trajectory. However, the repeated exposure to the same intersection in this study limits the conclusiveness of the findings. We thus developed a more flexible virtual environment allowing us to investigate the attention allocation and risk perception at various types of intersections.

2 METHODS

2.1 Participants

Twenty-five people participated in the study (44% females; age: 19-57 years, $M = 25$, $SD = 8$), voluntarily or in exchange for course credit. Most indicated to be skilled cyclists ($M = 3.7$, $SD = .9$, on a 5-point Likert scale).

2.2 Virtual environment and construction of intersections

Using the Unity engine, we developed a framework of consecutive 'tiles'. Intersection tiles consist of eight potential arms (i.e. point of entry, sharp left, 90° left, oblique left, straight, oblique right, 90° right, and sharp right). A software algorithm randomly selects between two and four arms (in addition to the point of entry, and with the additional constraint that there cannot be three or more adjacent accessible arms). The remaining arms are blocked and covered with building structures (see Figure 1, Panels A & B). The software randomly selects one of the accessible arms, which the participant is instructed to travel (see 2.2 Procedure). Connector tiles are placed in between two intersection tiles to convey the impression of a continuous urban environment, and to unobtrusively guide participants to the subsequent intersection tile's point of entry. Based on the underlying grid of these tiles, the algorithm constructs an environment consisting of route of up to six intersections of various layouts. The environment features a basic traffic simulation of pedestrians (walking on the curbs, crossing zebras, and occasionally stepping on the road from between cars parked along the road), cars and motorcycles traveling along all possible trajectories, as well as a varying density of parked cars.

Due to constraints imposed by the COVID epidemic, we could not use the same VR setup featuring a head mounted display as in [5]. We decided to adapt our study to a top-down perspective that participants could complete at home. A virtual bike is controlled with keys (i.e. accelerating, braking, turning left, and turning right), but remains in the center of the screen (with the environment shifting according to the participant's movement). The top-down perspective reveals more of the environment than would be visible from a first-person perspective of a given point-of-view. We were also interested to what extent participants would allocate their attention to intersections arms deviating more or less from their traveling direction. Thus, we implemented a 'gaze orientation', with the aim of approximating the actual human horizontal field of view. A virtual 'head' of the cyclist can be rotated to the left and the right with the mouse (limited to the frontal 180° in the current direction of travel). According to the head orientation, a horizontal field of view of 200° is visible, whereas the remaining area remains covered (see Figure 1, Panel C).

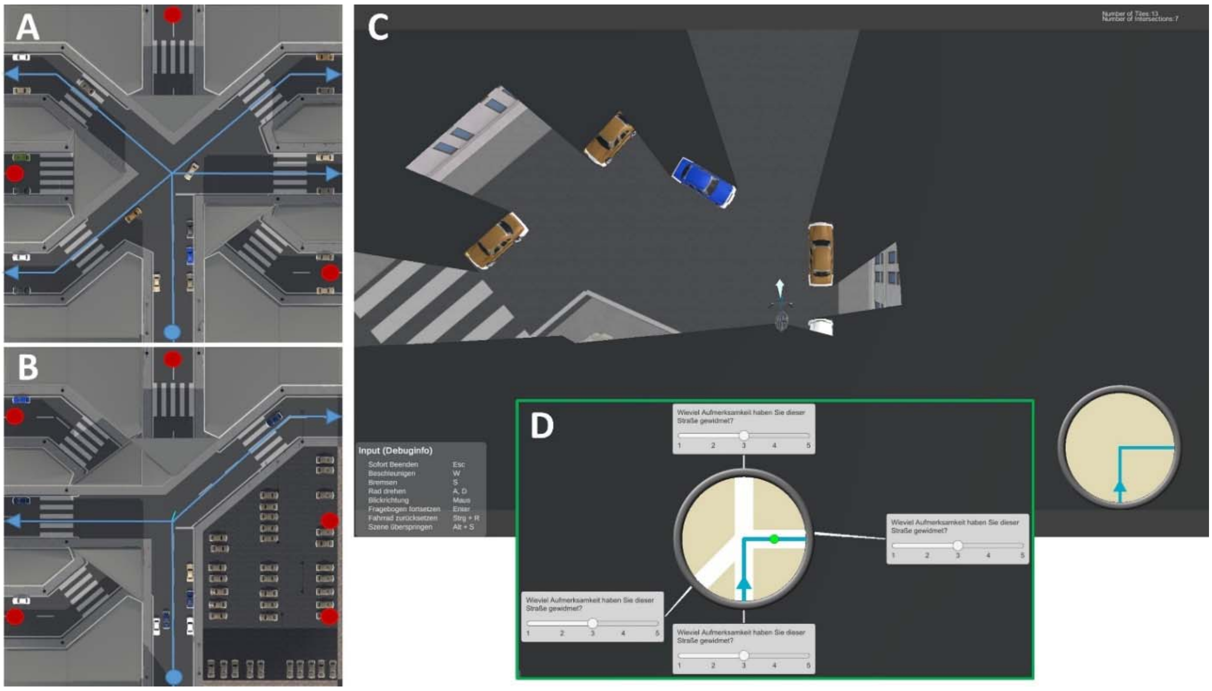

Figure 1. Panels A & B: Illustration of two intersection tiles. The blue dot indicates the participant's approach direction (always at the bottom). Blue lines and arrows indicate accessible intersection arms; red dots indicate arms that were blocked and covered in the respective instance. Panel C: Screenshot of the top down perspective as seen by the participants. The small bicycle indicates the current location. The light bluish arrow reflects the current travelling trajectory and speed. Only a frontal field of view of 200° is visible, all other areas are covered in black (as well as areas where the line of sight is broken, for example by one of the cars). The stylized navigation system in the right bottom corner indicates that the participant should take a 90° right turn (which is not visible from the cyclist's current position and gaze orientation). Panel D: The subsequent evaluation of the intersection shown in Panel C, consisting of an enlarged version of the navigation system, now showing all accessible intersection arms. Participants are requested to indicate the attention they allocated to each intersection arm on a 5-point Likert scale.

2.3 Procedure

Participants ran the study on their own laptops or computers. After providing informed consent, they were instructed to imagine that they were riding a bike at the presented intersections. For each intersection, a stylized navigation assistance system provided information about the correct traveling direction (without conveying information about the intersection's layout, see Figure 1, Panel C). After successfully navigating an intersection, participants were asked, first, to rate the hazard level of the entire intersection, and second, to estimate the level of attention they allocated to each of the intersection arms of this intersection, on 5-point Likert scales (see Figure 1, Panel D).

3 RESULTS

A first, descriptive overview of participants' hazard estimate for the entire intersection is presented in Figure 2. Intersections requiring a left turn were estimated to be more dangerous than those requiring a right turn.

Noticeably, the estimated danger increases drastically with each additional intersection arm located on the right side of the goal direction.

We aim to corroborate these observations with linear mixed models. Next to individual factors, we will consider the factors depicted in Figure 2 as well as possible interactions. We will also consider random factors such as the number of cars etc. A corresponding analysis will be conducted for the reported attention allocation to the individual intersection arms. We will try to extract further information about the participants' attention allocation by determining how many times they turned their virtual head into the direction of an intersection arm, as well as by counting the gazes into different directions when crossing the intersection.

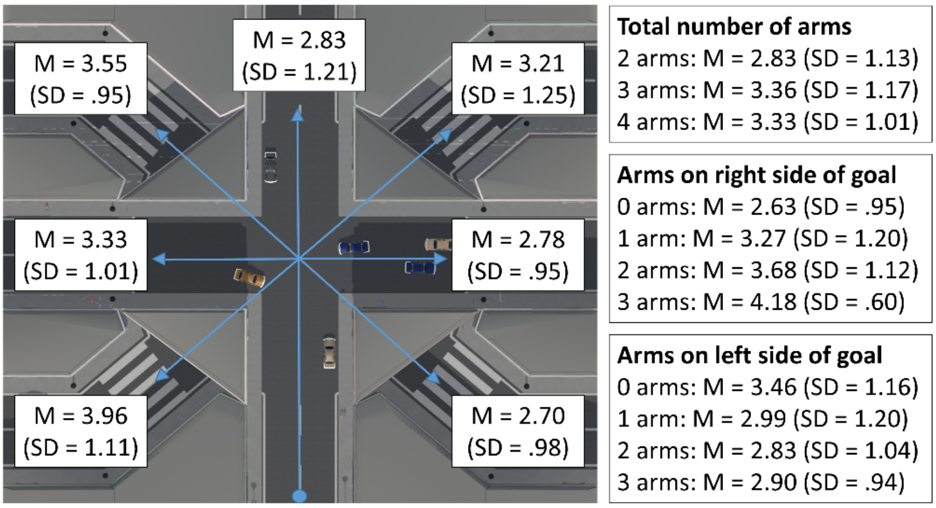

Figure 2. Means (and standard deviations) of the hazard estimate for the entire intersection, separately for the different goal directions, the total number of intersection arms, as well as the number of arms left or right of the goal direction.

4 CONCLUSIONS

Our study requires participants to deal with intersections featuring diverse layouts concerning the number and orientation of intersection arms. It is thus suited to provide insights into the features (e.g. the position relative to the cyclist, the required turning type, and the overall complexity) attracting a cyclist's attention, and how these features affect the cyclist's level of subjective safety. The presentation format of a top down perspective is obviously rather different from that of a cyclist in the real world. However, we adjusted the field of view in our study to make it resembling a first-person perspective to some extent. Our findings can provide information that guide future investigations of cyclists' behavior at complex and irregular intersections.

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Analysis of the consequences of car to micromobility user side impact crashes

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Keywords: micromobility, vulnerable road users, safety, simulation.

1 INTRODUCTION

Mobility has changed in recent years in cities worldwide, thanks to the strong rise in vehicles of micromobility. Bicycle riding is the most widespread micromobility transport mode, followed by stand-up electric scooters (e-scooters). This increase in its use has also led to an increase in related crashes. Both cyclists and e-scooter riders are vulnerable road users and are likely to sustain severe injuries in crashes, especially with motor vehicles.

The crashes consequences involving cyclists and other micromobility users have already investigated using numerical simulation software, such as MADYMO and PC-Crash. Most of them have been focused on bicycles and electric bicycles, whereas only few of them have analyzed e-scooter crashes consequences. Posirisuk et al. [1] carried out a computational prediction of head-ground impact kinematics in e-scooter falls. Ptak et al. [2] analyzed the e-scooter user kinematics after a crash against SUV when the e-scooter drives into the side-front of the vehicle, a side B-pillar crash and a frontal impact initiated by the e-scooter to the front-end of the vehicle. However, they did not study the consequences of a car to e-scooter side impact crashes. Xu et al. [3] did study these crashes but considering electric self-balancing scooters that are less widespread than e-scooters.

Current study focuses on the consequences of a car to micromobility user (cyclist and e-scooter rider) side impact crashes. The analysis is based on numerical simulations with PC-Crash software.

2 METHODOLOGY

In order to assess the consequences of a car to micromobility user side impact crash, different scenarios have been simulated with PC-Crash software (see Figure 1). PC-Crash is a crash reconstruction program allowing the user to perform simulations with multibody objects that collide with 3D vehicle mesh models [4]. In the current study, a bicycle (length: 1.821 m, width: 0.6 m, height: 0.992 m, weight: 15 Kg), an e-scooter (length: 1.180 m, width: 0.680 m, height: 1.232 m, weight: 16 Kg) and their riders (height: 1.75 m, weight: 80 Kg) multibody systems have been used. The vehicle model corresponds to a Ford Focus 2.0 TDCi (length: 4.340 m, width: 1.840 m, height: 1.490 m, weight: 1300 Kg, wheelbase: 2.640 m).

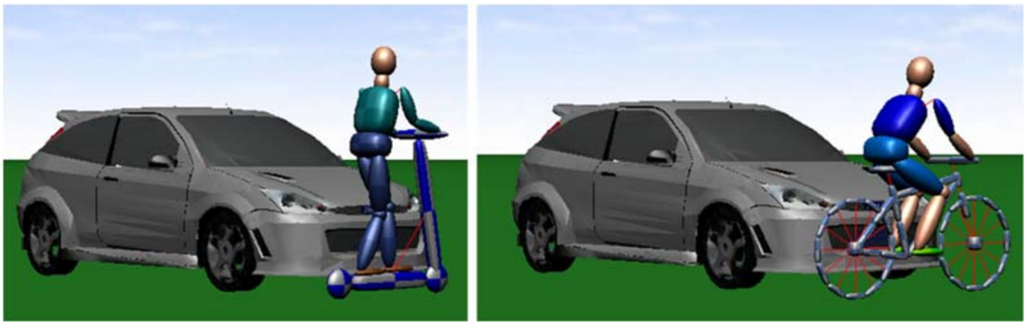

Figure 1: Scenarios simulated with PC-Crash.

Traffic crash scenarios simulate lateral impact at a right-angle intersection. Numerical simulations have been conducted at various motor-vehicle impact speeds (from 25 km/h to 50 km/h). The results of these simulations have been analyzed considering the chest acceleration and the HIC (head injury criterion). Federal Motor Vehicle Safety Standards adopted HIC as injury criterion with the safety margin of HIC15=700. Besides, 3 millisecond chest acceleration criterion has also been considered, whose safety threshold is 60 g, according to FMVSS 208.

3 RESULTS

Considering the results of the simulations, the variation in the chest acceleration and in the HIC15 as a function of the motor-vehicle speed has been studied (see Figure 2). In the case of chest acceleration, the 60 g threshold is never exceeded. However, when a car-e-scooter crash occurs at 50 km/h the chest acceleration is closed to 50 g, that can be considered very high value. On the other hand, both in car-e-scooter crash and in car-bicycle crash, HIC increases as motor-vehicle speed increases. When the car approaches at 45 km/h, in both cases the HIC exceeds the safety margin of 700, being in any case higher when the crash is between the car and the e-scooter.

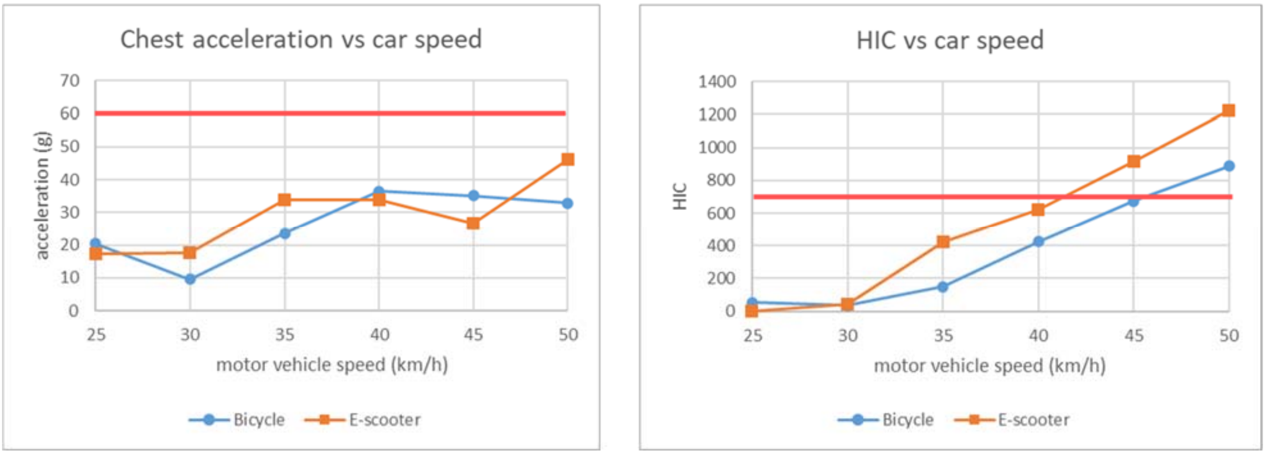

Figure 2: Variation of chest acceleration and HIC as a function of motor vehicle speed..

4 CONCLUSIONS

The mobility patterns and lifestyles have changed thanks to the strong rise of micromobility, especially bicycles and e-scooters, becoming a serious safety concern. The risk of a crash is greater at intersections and their severity is also greater there due to the interaction between micromobility vehicles and motor-vehicles.

The consequences of a car to micromobility user (cyclist and e-scooter rider) side impact crash have been analyzed based on the results of different scenarios simulated with PC-Crash. Results showed that riding a bicycle is safer that riding an e-scooter since the observed HIC is lower. However, in both cases, motor-vehicle speeds close to 45 km/h increase probability of serious injury and even death of the rider.

ACKNOWLEDGEMENTS

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Determinants of Bicycle Crashes at Urban Signalised Intersections

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Keywords: bicycle safety, urban intersections, safety-in-numbers, design.

1 INTRODUCTION

Bicycle usage is increasing in urban (as well as rural) areas, which increases demand for better and safer infrastructure. Whilst the total number of bicycle fatalities in European countries has been stable over the last ten years (≈ 2.000 fatalities per year for all European Union member states [1]), bicycle fatalities and injuries in Germany have been increasing in this time [2]. About two-thirds of all bicycle crashes in Germany occur at intersections, this proportion is higher than in Denmark and the Netherlands (three-fifths) [3]. Intersections are thus of high relevance for bicyclists' safety and in addition, they require sophisticated research methods because of their complex designs and the high numbers and types of user interactions and conflicts compared to street sections. This study analyses determinants of bicycle crashes at 269 signalised intersections in two major cities in Germany (Dresden, Munich) as the basis for developing evidence-based recommendations for improving bicyclists' safety at existing intersections and for ensuring high safety levels at newly planned intersections from the very beginning. This study is part of the research project SiRou (nrvp.de/21520). The project is funded by the German Federal Ministry for Digital and Transport within the National Cycling Plan 2020 (NRVP).

2 METHOD

This study is based on a unique set of data in terms of infrastructure characteristics and exposure. Municipal transport authorities contributed georeferenced positions of all signalised intersections and volumes of motorised vehicles. The latter were provided as the total Annual Average Daily Traffic (AADT). Bicycle volumes were computed by combining crowd-sourced bicycle trajectory data (collected in *City Cycling 2019* [4]) and extrapolation factors derived from permanent automatic counting stations.

Intersection characteristics in terms of design and operation were gathered from OpenStreetMap (OSM), municipal transport authorities as well as from aerial photos and image databases (e.g. Mapillary), and were matched to the georeferenced intersections in a GIS database. Data on infrastructure characteristics were collected either per arm or per intersection. Characteristics that differed by arm were aggregated to one percentage value per intersection (e.g. 50 % of intersection arms operate with a separate left turn phase).

Intersections were categorised based on the types of bicycling infrastructure into minor, medium and major intersections (see Figure 1). Minor intersections have no bicycling infrastructure, medium intersections have bicycling infrastructure on the main road and major intersections have bicycling infrastructure on each arm.

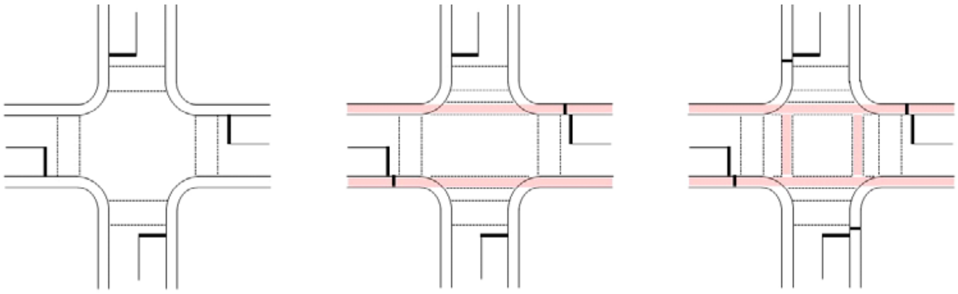

Figure 1: Intersection Classification

Asymmetrical intersections with bicycling facilities on either one or three arms were assigned to the respective lower level in the classification. Data for a total of 269 intersections was collected and analysed.
Bicycle crash data was taken from the open *Interactive Accident Atlas* published by the federal statistical office of Germany [5] for a five-year period (2016-2020). The final database consists of 1,218 bicycle crashes.
Crash data and its correlates were analysed using Accident Prediction Models (APM). The effects, that are described below, are all multivariate and significant in these APMs at a significance level of 5 %.

3 RESULTS

The APM for the total number of bicycle crashes at the entire intersection including minor, medium and major categories shows significant effects for the exposure variables (bicycles and motorised vehicles), signalling and type of intersection (see Table 1). Bicycle volumes influence the predicted bicycle crash number with a coefficient of 0.521, which is consistent with recent studies [6,7] and confirms the safety-in-numbers hypothesis for bicycle traffic [8,9]. The coefficient for motorists volumes is with 0.782 higher than for bicycle volumes.
The significant negative coefficient for the share of arms with separate right turns has not been found in other studies yet but shows that the separation in time significantly improves bicyclists' safety at the investigated intersections.
The type of intersection also significantly impacts on the predicted bicycle crash numbers. Major intersections have the highest and minor intersections the lowest safety levels. This means that the more intersection arms are equipped with bicycling infrastructure, the safer the intersection is as a whole for bicyclists also with consideration of bicycle volumes.

Table 1: Regression Coefficients and Significance Levels of Entire Intersection APM

Feature	Unit	Regression coefficient	Significance Level
Constant Term	[-]	-12,423	0,000
ln(AADT_bic)	[bic/24h]	0,521	0,000
ln(AADT_mot)	[mot/24h]	0,782	0,000
Sep. right turn	[%]	-0,570	0,006
Classification	Minor	0,383	0,007
	Medium	0,237	0,024
	Major	0,000	

No infrastructure characteristics get significant in the model because many of them (e.g. type of bicycling infrastructure) correlate with the intersection category. Still, the model fits well (variance explained: 59 %).

Separate models were developed for each intersection category in order to investigate possible influences of the infrastructure characteristics on the number of bicycle crashes.
The APM for the major intersections shows, similarly to the entire intersections model, significant effects of bicycle and motorists volumes as well of the separate right turn phase. Additionally, the distinction between three-arm and four-arm intersections is significant: Three-arm intersections are safer, this is plausible seeing their lower number of conflict points.
Besides, the type of bicycling infrastructure (mandatory bicycle lane vs. bicycle track vs. combination of both) significantly influences the predicted crash numbers: bicycle lanes approaching the junctions are the less safe than bicycle tracks. The presence of bicycle tracks reduces the crash number by a factor of ($\approx e^{-0,7} \approx$) -50%. This effect was hardly found in the literature: one German descriptive study found reverse effects with bicycle lanes being safer than bicycle tracks [10]. Other factors such as the presence or width of a bend-out did not get significant, they strongly correlate with the distinction between bicycle tracks and lanes.
The medium- and minor-intersection model each show similar results.

4 CONCLUSIONS

The significant effects of bicycle volumes on bicycle crash numbers in all models clearly support the safety-in-numbers hypothesis with coefficients between 0.45 and 0.52. Motorists volumes are also significant in each model and consistently show higher coefficients than bicycle volumes. Increasing bicycle volumes or decreasing motorists volumes by bundling bicyclists away from heavily frequented intersections may thus increase safety. The type and quantity of bicycling facilities are the main significant infrastructural variable, the models show that more bicycling facilities at intersections improve bicyclists' safety. This result supports preferences for dedicated bicycling facilities at intersections for improving bicyclists' safety compared to having bicyclists and motorists sharing the same space in the carriageway. These findings are not in line with the current German practice and guidelines for designing bicycle facilities at intersections. These recommend to have bicycling facilities in the carriageway or next to the carriageway in order to increase bicyclists' visibility and thus also safety. The models in this study, however, show that bicycle tracks in combination with a separate right turn phase for motorists are the safest type of bicycle infrastructure at the investigated intersections. There is no clear indication about the influence of the degree of bending-out bicycling facilities. Possible differences between the two cities Munich and Dresden will be investigated in the next months.

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Characterization of micromobility crashes in Spain (2016-2020)

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Keywords: micromobility, crash, safety, bicycle, e-scooter.

1 INTRODUCTION

Micromobility has a direct impact on the urban area, since it tries to make cities more liveable, offering an alternative transport option that contributes to reduce air and noise pollution. Additionally, it promotes intermodality, promotes money savings, reduces parking space and helps to avoid road congestion in cities that have their own lanes for the use of micromobility vehicles such as bicycles, stand-up e-scooters (e-scooters) and other personal mobility vehicles (PMVs) [1, 2].

In Spain, micromobility has significantly increased in recent years, through the increase in the supply and demand for bicycles and other PMVs, mainly e-scooters.

There are many reasons that have motivated users to prioritize the bicycle and the other PMVs over other means of transport. In addition to the growing concern for health and the environment, the COVID-19 pandemic has also driven the growth in the use of the different PMVs in 2020 [2, 3]. According to data from Global Public Transport Report [4], published by the mobility application Moovit, 31% of Spaniards have used bicycles, scooters or e-scooters in 2020, increasing their use by 7% since 2019.

However, in parallel and because of the increase in PMVs exposure, the number of crashes involving users of these vehicles has also increased in recent years. For this reason, among road safety researchers, interest and concern for the study of this kind of crashes have also increased.

The aim of this research is to characterize the crashes in Spain in which at least one PMV (bicycle, e-scooter or other PMV) is involved between the years 2016 and 2020.

2 DATA BASE

The crash data bases of the General Directorate of Traffic (DGT) of these 5 years have been used for this research. From these, the e-scooters and other PMVs involved in these crashes have been identified and classified in the following categories: (1) “e-scooters”; (2) “other PMVs”, which includes segways, skateboards and electric wheelchairs; and (3) “unspecified PMV”, which includes those vehicles that are for personal mobility, but it is not possible to know what type according to the available data.

3 RESULTS

In Spain, between 2016 and 2020, 305,689 crashes took place on urban roads. Of these, a total of 29,913 crashes involved at least one PMV (including bicycles and other PMV). Figure 1 shows the evolution of the number of bicycles and other PMVs involved in crashes and the evolution of micromobility crashes over the analysed period. The number of bicycles involved in these crashes has remained approximately stable over these years, although with a slight decrease. However, a clearly growing trend is observed in the rest of PMVs analysed, especially in recent years. The number of micromobility crashes evolution follows a trend similar to the number of bicycles involved in these crashes until 2018, when the number of micromobility crashes began to increase, coinciding with the year when the other PMVs involved in crashes started to increase.

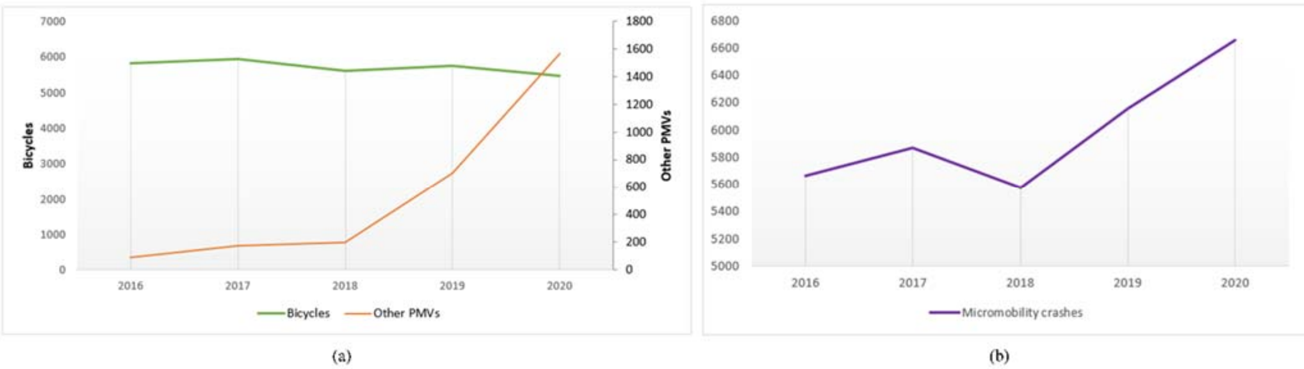

Figure 1: Evolution of micromobility users (a) and crashes (b) in urban areas in Spain (2016-2020).

The stagnation of the reduction in the number of bicycles involved in crashes, as well as the increase the rest of PMVs involved in these collisions and the micromobility crashes, have motivated this research. In this study, these crashes have been characterized through their severity, the day they occurred, the type of crash and whether it occurred at an intersection.

The micromobility crashes occur mainly on working days and almost 35% of them involved only PMVs. The main types of crashes are side-impact collisions. However, accidental falls, pedestrian collisions and sideswipe collisions are also important. Moreover, 44.05% of the crashes took place at intersections and they are slightly more serious. Therefore, research should focus on these locations to minimize the amount of these crashes and their severity.

Figure 2 shows the distribution of micromobility crashes in Spain, considering the involved user, from 2016 to 2020. In 2016 there were a higher proportion of crashes between PMV and motorized vehicles and a lower proportion of crashes in which only one PMV was involved. Nevertheless, the evolution of micromobility crashes in Spain remained approximately stable until 2020.Compared to 2019 data, in 2020 the proportion of crashes involving only one PMV has increased by more than 6.7% and the proportion of collisions between PMVs by almost 1%. However, the proportion of crashes between PMVs and pedestrians decreased by 1.66% and there was also a 5.89% reduction in the proportion of collisions between PMVs and motorized vehicles compared to 2019.

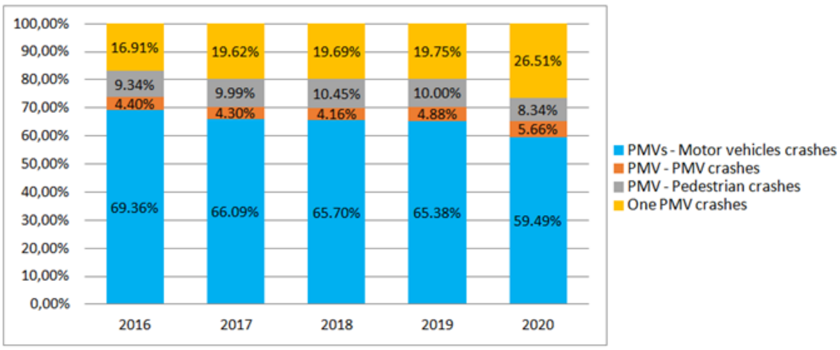

Figure 2: Distributions of users involved in micromobility crashes (2016-2020).

Regarding crash severity based on the user involved, the results show that most micromobility crashes are slightly or seriously injured (more than 90%) and less that 10% are fatal crashes. Most of micromobility fatal and seriously injured crashes occur between PMVs and motor vehicles. However, there is also a high proportion of crashes involving only one PMV (Figure 3). Therefore, further research about this type of collision is needed.

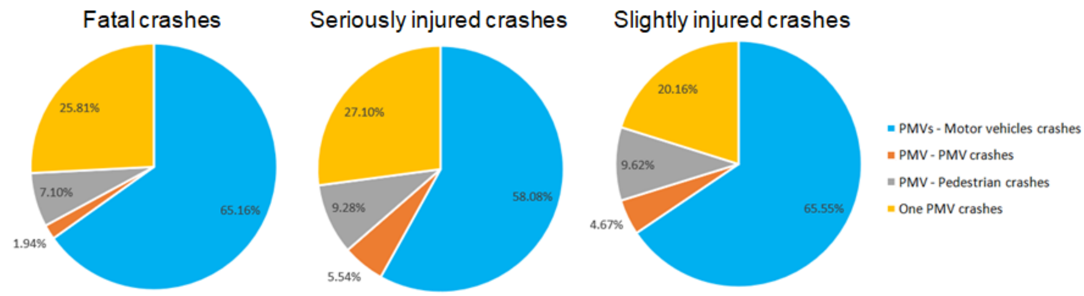

Figure 3: Micromobility crashes distribution based on severity and users (2016-2020).

The distribution of the crash types involving only one PMV is shown in Figure 4, where it can be seen that the most frequent crashes have been due to falls (57.57%) and overturning (19.32%).

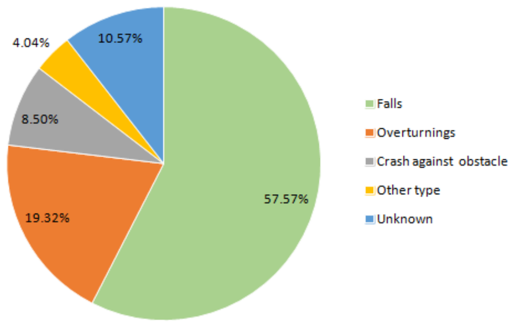

Figure 4: Crash types distribution involving only one PMV in Spain (2016-2020).

4 CONCLUSIONS

In recent years there has been an increase in urban crashes involving at least one PMV. Although the number of bicycles involved in these crashes has remained approximately stable, the presence of the rest of PMVs and its crashes has increased significantly, especially since 2018. In this research, an analysis of these crashes has been carried out with the aim of characterizing them.

Results showed that most severe crashes occur at intersection and between micromobility users and motor vehicles. However, a significant proportion of seriously injured and fatal crashes are those that involve only one bicycle or other PMV riding alone. Therefore, further research about the causes and consequences of this kind of crashes is needed. Research should also focus on crashes involving pedestrians, since, although they do not represent a large percentage of crashes, pedestrians are the most vulnerable users.

ACKNOWLEDGEMENTS

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Automated Shuttles as Traffic Calming: Evidence from a Pilot Study in City Traffic

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Keywords: automated shuttles, safety, cyclists, pedestrians, traffic calming.

1 INTRODUCTION

Discourse about the real-world effects of automated vehicles has intensified over the last decade, but few observational studies have been made examining their integration in real traffic. This research is based on the dataset prepared by Beauchamp et al. in [1] where video footage from two pilot projects involving automated shuttles in Montreal and Candiac in 2019 was analyzed to compute safety indicators from road user trajectories. The study showed that automated shuttles have safer interactions with other road users compared to human drivers following the same trajectories.

Yet, this may not be the only characteristic of automated shuttles. These vehicles are notoriously slow, 10 to 15 km/h slower than human-driven cars in city traffic [1], which on city streets is bound to influence other road users, in particular following cars. It is therefore hypothesized that automated shuttles may have a traffic calming effect, slowing other motorized vehicles [2]. Slower speed and the predictability of automated shuttles, obeying the rules of the road and yielding more willingly to vulnerable road users (pedestrians and cyclists) may also have an impact on these users' behavior [3]: for example, cyclists may pass the shuttle, pedestrians may cross outside of crosswalks. The present study aims to explore the potential effects of automated shuttles, with their slower speeds and more predictable behavior, on the behavior of other road users.

2 METHODOLOGY AND EXPERIMENTAL RESULTS

This work relies on the extracted trajectory data from the study of Beauchamp et al. [1], where the trajectories of all road users were extracted for more than 70 hours on seven sites along the shuttle routes, three in Montreal and four in Candiac (south shore of the Island of Montreal). The exploratory analysis presented in this paper relies on 2 hours and 40 min of observations at two sites in Montreal. Road user speeds and accelerations are compared by category of road user, depending on the presence of the automated shuttle and the time since it passed. Various statistics of each individual road user trajectory can be extracted: the mean speed, as well as the 15th and 85th centiles of acceleration, are computed for each road user. The 15th and 85th centiles of acceleration are generally negative and positive respectively, corresponding to "extreme" braking and "accelerations" by each road user as it passes in the camera field of view.

The mean speeds are show in Figure 1 for two sites in Montreal. The first boxplot in each sub-graph (indexed by "0") corresponds to the speeds of each category of road user for road users in the presence of the automated shuttle. In both sites, the mean speeds of cars (the medians and most of the other quartiles) are lower than for time intervals after (e.g., the $]0-1]$ interval corresponds to the mean speeds of cars passing between 0 and 1 min after the shuttle). This would be consistent with a calming effect on cars that must interact with the automated shuttle. There are few observations for other road users at the second Montreal site (Ontario). For cyclists at the Coubertin site, the trend seems different, with higher speeds for cyclist interacting with the shuttle. The speeds of pedestrians do not seem to change depending on the presence of the shuttle, except for reduced variability as measured by the interquartile range (but the sample size is the smallest for pedestrians in the presence of the shuttle).

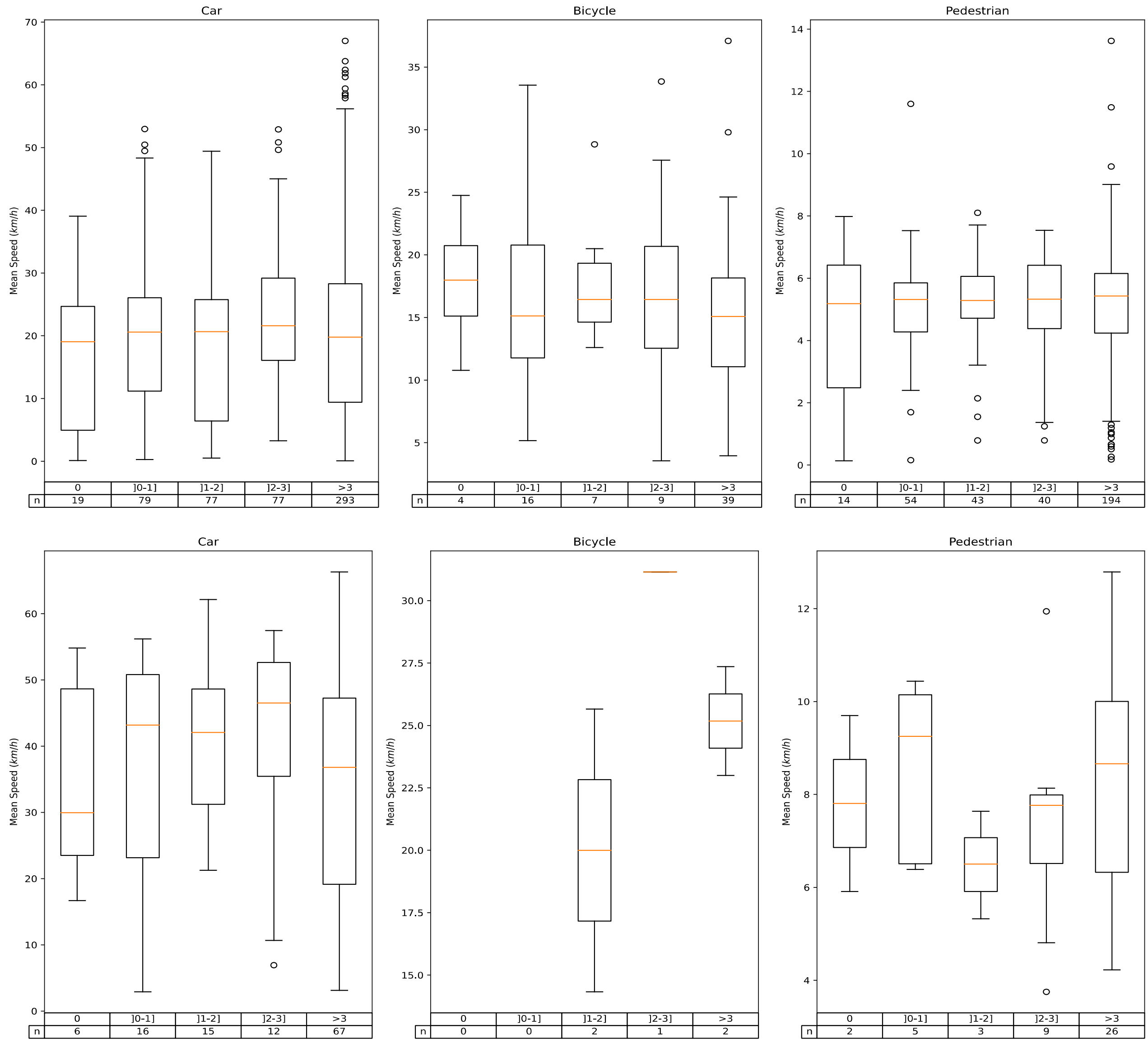

Figure 1 Boxplots of mean user speed per category of road user for different time intervals (in min) since the shuttle passed ("0" means the shuttle was present when the road user passed) at the Coubertin (top) and Ontario (bottom) sites in Montreal (n in the table denotes the number of road users per time interval).

Accelerations and brakings (i.e., the 85th and 15th centile of accelerations) are shown in a similar way for the Coubertin site in Figure 2. The results seem even clearer for cars, with higher accelerations and especially lower brakings (larger in magnitude) after the shuttle has passed. The variability of the brakings also increases with more extreme low brakings beyond the whiskers. As for speeds, cyclists in the presence of the shuttle have higher accelerations or lower brakings. For pedestrians, the trend is a bit clearer, with slightly higher accelerations and lower brakings after the shuttle passage. This would also be consistent with a traffic calming effect of automated shuttles, as cars react less strongly in its presence, while pedestrians have to accelerate / brake more strongly after its passage when car traffic is faster and more "aggressive". The behavior of cyclists is more complicated to interpret.

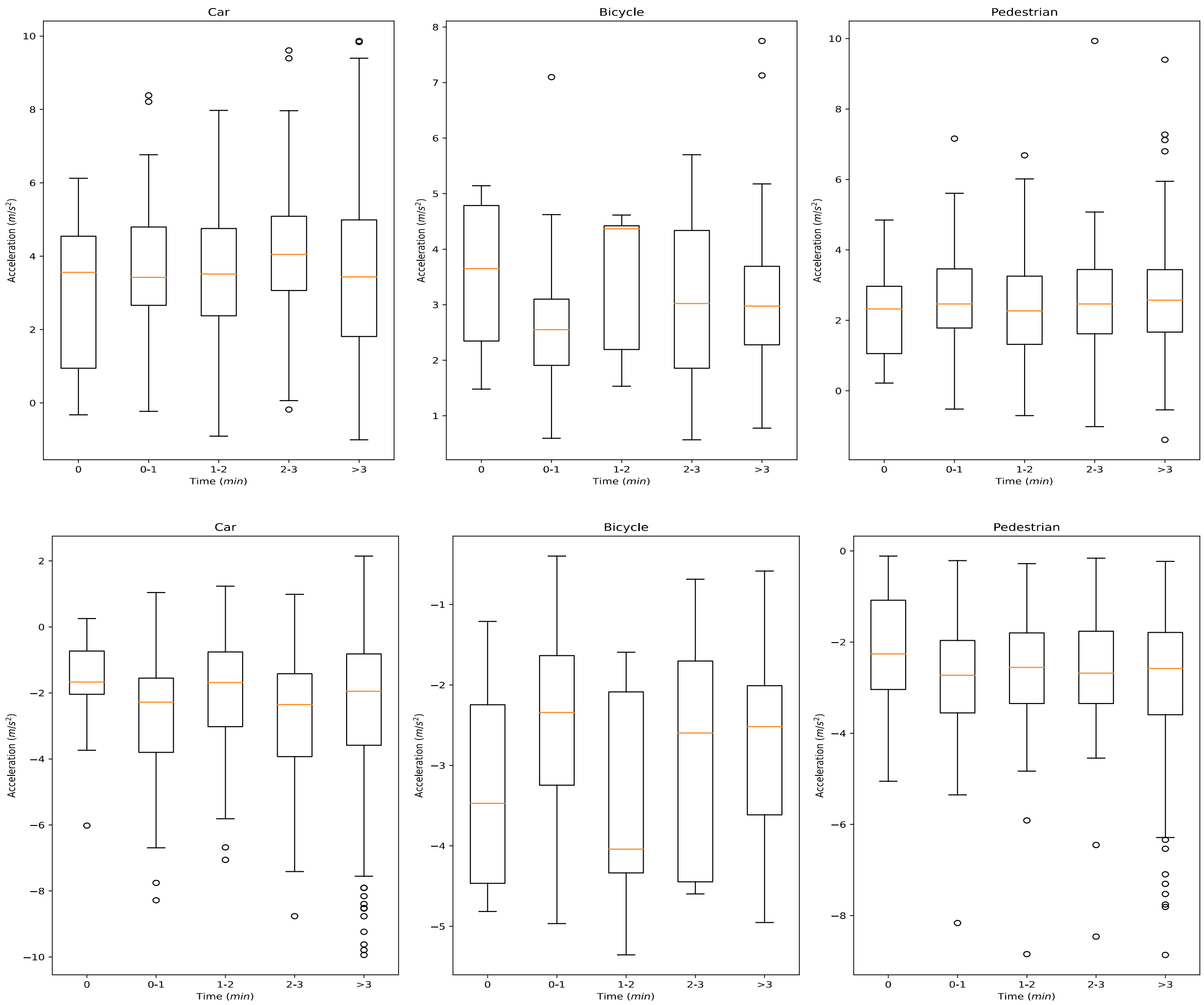

Figure 2 Boxplots of 85th and 15th centiles of acceleration (respectively top and bottom) per category of road user for different time intervals (in min) since the shuttle passed ("0" means the shuttle was present when the road user passed) at the Coubertin site.

3 CONCLUSIONS

The first results of this exploratory analysis point toward an effect of automated shuttles on the behavior of other road users, with slightly lower speeds and less harsh accelerations for cars. More analyses are needed to characterize and understand the behavior of cyclists and pedestrians, including in terms of their maneuvers and spatial distributions in the presence of the automated shuttle.

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Measuring exposure for cyclists and micro-mobility users

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Keywords: cycling, e scooters, travel behaviour survey, bicycle counters, app data, video observation

1 INTRODUCTION

Data about bicycle usage is an important input parameter for several purposes. They are used to describe changes towards more sustainable transport, and partly to say something about changes towards more active transport as opposed to passive modes of transport. Importantly such data are used as the denominator when calculating crash risk for cyclists. In Norway, as in most countries, these data are captured in several ways today. This is partly done by using data from the national travel behavior survey, partly using figures from stationary or mobile bicycle counters, and partly using other methods such as manual counts, etc. The technological development has provided several new opportunities to register such travel, in the form of more advanced stationary counters, advanced algorithms that interprets signal data, video recording solutions and app-based measurement systems.

At the same time, we see that development in the transport sector also creates new challenges. In just a few years, electric scooters have radically changed the traffic picture in cities and towns in Norway. There is therefore a need for more knowledge about different forms of ways to measure bicycle and micro-mobility use, their strengths and weaknesses, and what kind of strategies the authorities should have to be equipped to meet future changes in the transport field, as exemplified by the recent influx of e-scooters.

The current paper aims to respond to these challenges by answering the following research questions:

- What are the relative strengths and weaknesses of different data sources for measuring cycling and micromobility use?
- How well do the different sources function to capture micromobility and to differentiate between traditional cycling and micromobility?
- How can the different data sources be used as input for calculating crash risk for various forms of soft mobility (i.e. cycling and micromobility)?

2 METHODS

As a preparation for collecting and analysing empirical data, a scoping review as well as interviews with key stakeholders working with measuring cycling in Norway, Sweden, Denmark and the Netherlands were performed. The purpose of these was to give an account of State of the Art, recent advancements, as well as strategic initiatives for measuring cyclists and micromobility.

The study uses a variety of data sources to respond to these questions. The first is existing data from various travel behavior surveys. In Norway, national travel behavior survey (RVU) is conducted on a regular basis. The RVU has been conducted in Norway approximately every four years since 1984/1985. From 2016, continuous RVUs have been conducted, which only really got underway in 2018. That is, there are national travel behavior data for 1985, 1992, 1998, 2001, 2005, 2009, 2013/14, 2018/19 and 2020. Ruter (the regional Public transport provider for the capital region) has had rolling travel behaviour survey running since 2005, which also captures cycling and (potentially) micromobility (since 2019). Another survey resource is a number of studies more specifically aimed at capturing level of micromobility usage in the population in 2019, 2020 and 2020.

Data from Oslo city council's program of inductive counting loops (N=44), as well as the public road authorities' (NPRA) counters (N=4) are pooled and used as measures of cycling activity. For municipal data the number of counting stations included in the data material varies from year to year. In addition, data from municipal counters at locations in three other smaller towns were included.

The third empirical data source is data from series of studies using video recordings of traffic and annotated with the software program Road User Behaviour Analysis (RUBA), or manually. Video data was collected using a Miovision Scout camera. Data on traffic volumes were captured with RUBA software [1]. A presence detector created in RUBA provided a print screen every time an object crossed the detector. In final step, these print screens were manually sorted to distinguished between cyclists and e-scooters.

The fourth data source is data collected with a mobile phone app [2]. The app (Sense.DAT, Mobidot) is a travel behaviour app that maps route choices and mode choice. This is a "self-learning app" that records travel outside the house. The app uses the phone's positioning service to locate the mobile. The position may be determined by cellular network, Wi-Fi network and GPS data, or a combination of these. The automatic categorization of travel modes is based on an algorithm that looks at the characteristics of the individual trip, such as speed and route selection. In addition, it can utilize several other sensors in the mobile phone, such as accelerometers. According to the supplier, the algorithm has an accuracy of 90 percent when identifying bike trips.

3 RESULTS

As an example of how well the different data sources are suitable for capturing micromobility and to differentiate between traditional cycling and micromobility we can look at two data sources, travel behavior surveys and inductive loop counters, and see how well these capture *changes in cycling over time* (figure 1). The data are indexed so that year 1 (2014) is set to the value 100.

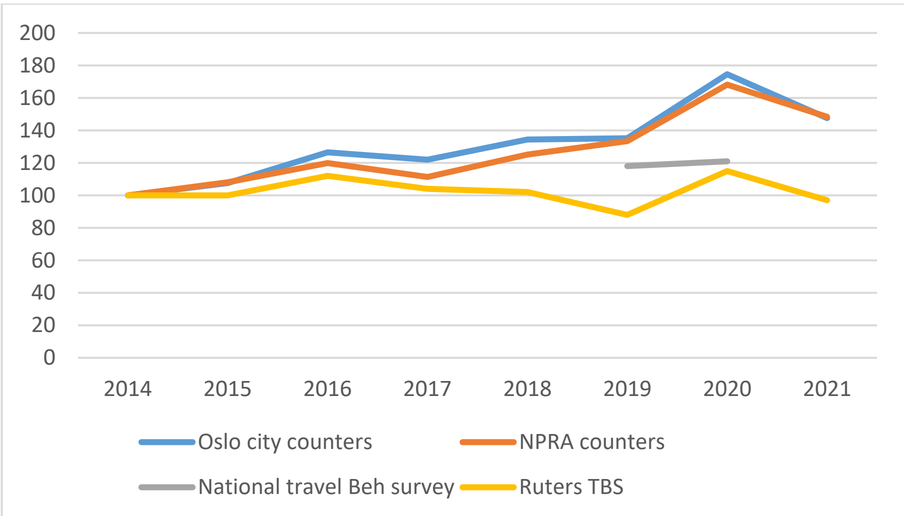

Figure 1 comparison of two counter sources and two survey sources for measuring cycling.

As we can see there are large discrepancies in the assessed increase in cycling is in Oslo is, depending on source. The inductive loop counters estimate an increase of up to 75 % from 2014 to 2020, whereas the increase is only 21 % according to the survey data.

Another analysis we have made is an assessment of how well an inductive loop counter (Eco Counter) performs as a counting device for cyclists and micromobility compared to a simple video-recording software (RUBA) .

Figure 2 shows the example of hourly numbers of detected road users in a bicycle lane during Thursday, June 2021 at one of five locations that are analysed.

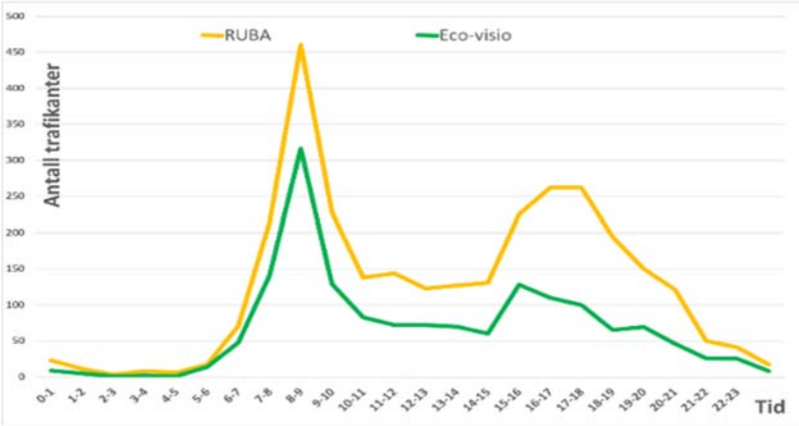

Figure 2 comparison of Eco Counter and video data for measuring and micromobility (Thursday, June 2021).

At this location on Thursday, Eco-Counter detected 53 % of all RUBA based detections from the video recording. The main reason for the large discrepancy is that Eco-Counter does not count e-scooters. If we only look at counts of cyclists, Eco-Counter still has a lower detection rate, as it detected 84% of the cyclists that RUBA counted. Sensitivity tests (using manually counts from video) under different traffic conditions and lightning conditions showed that RUBA was sensitive to these conditions, but that the performance was still well above acceptable limits –combination of RUBA and manual recognition of detections identified more than 99 % of cyclists and above 95 % of e-scooters in the most challenging observational times (night; rush hour).

When comparing app data with data from a travel behavior survey, the app recorded substantially more km, minutes and non-zero trip days than the one-day survey. On the individual level there was a tendency for the app to register modes not self-reported by the respondents for all modes except public transport, possibly indicating that the app captures trips that the user may have forgot or intentionally left out. For bike the Spearman correlations between app and survey registered (one-day) distances and durations were moderate ($r > 0.5$) or strong ($r > 0.8$) when based on observations that were non-zero in both data sources, and moderate or weak when based on all observations.

Further analyses, looking at different generations of counting loops as well more detailed accounts of how the various sources functions to capture risk exposure will be presented at the conference.

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Can light passenger vehicle trajectory better explain the injury severity in crashes with bicycles than crash type?

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Keywords: cyclist injury severity, crash type, trajectory type, intersection, mixed logit model.

1 INTRODUCTION

Movements of cyclists and motor vehicles at intersections involve a wide variety of potential conflicting interactions. In Australia, the high numbers of motor vehicles, particularly light passenger vehicles, mixed with cyclists results in many bicycle-light passenger vehicle (LPV) crashes (3,135 crashes during 2002-2014). About 68% of cyclist deaths at Australian intersections in 2016 were due to crashes between bicycles and LPVs (DITRLDG, 2016). The high number of LPV crashes among fatalities among cyclists is an increasing safety concern. When an LPV collides with a cyclist, the resulting impact forces influence the probability of cyclist injury severity outcome. Therefore, the goal at intersections should be to understand whether and which particular crash patterns are more injurious, in order to better inform approaches to reduce the impact forces to levels that do not result in severe injury outcomes.

To examine how crash pattern (or mechanism) influences the injury severity of cyclists in bicycle-motor vehicle crashes at intersections, researchers typically describe the crash mechanism in terms of crash types, such as angle crashes, head-on crashes, rear-end crashes, and sideswipe crashes (e.g., Kim et al., 2007; Pai, 2011). While crash types explain crash mechanisms to some extent, this study hypothesizes that the trajectories of the crash involved vehicles may provide additional information because they better capture the movements of the vehicles prior to collision. Furthermore, it is argued that injury pattern might be influenced by vehicle travel direction and manoeuvre (Isaksson-Hellman and Werneke, 2017). For example, when a car is moving straight ahead it is likely to have a higher speed than when it is turning, and if cyclists are struck at a higher impact speed, they tend to sustain more severe injury (Badea-Romero and Lenard, 2013).

While many studies have evaluated the association between cyclist injury severity and crash types, the factors that might influence cyclist injury severity related to trajectory types (vehicle movement and travel direction) have not yet been thoroughly investigated. This study aims to examine the factors associated with cyclists' injury severity for 'trajectory types' compared with the typically used 'crash types' at intersections.

2 DATA AND METHOD

This research was conducted in Queensland, the second largest Australian state. The climate in Queensland is temperate, with warm summers and mild winters, which enables cycling all year round. Police reported LPV crashes which involved at least one cyclist and in which someone was injured were included in this study.

2.1 Crash data

A total of 3,135 bicycle-LPV crashes occurred at intersections over the study period (2002-2014). These crashes were categorised by the authors of this paper into 24 combinations of movement types in five crash groups: (i) a straight same direction collision is defined as a collision which takes place when an LPV proceeding straight ahead collides with a cyclist who is travelling in the same direction; (ii) a straight opposite direction collision is defined as a collision which occurs when a cyclist and an LPV approach each other while travelling straight ahead but from opposite directions; (iii) a turning same direction collision is defined as a collision which occurs when a turning LPV collides with a cyclist travelling in the same direction; (iv) a turning opposite direction collision is defined as a collision where a turning motorist strikes a cyclist travelling in the opposite direction; (v) a straight right angle collision is defined as a collision which the colliding motor vehicle driver and cyclist were travelling straight ahead from two intersecting roadways. These groups are referred to as ‘trajectory types’ hereafter.

2.2 Statistical analysis

Following a descriptive analysis of the crash data, two mixed logit models (MXL) of cyclist injury severity were calibrated: (1) using the crash type variable, and (2) using the trajectory type variable. Based on a review of the literature, other variables related to the cyclists, crash locations, road geometric characteristics, traffic characteristics, and atmospheric conditions were also included in both models as explanatory variables. Model calibration was done in the LIMDEP software package. It is noted that the mixed logit model has been used in other injury severity studies and well accepted to model injury severity.

3 RESULTS

Some of the key descriptive statistics are presented in Table 1. Since the number of fatal injuries (n=37) is low, the two highest severity levels were combined to avoid computational issues in estimating the MXL models. Straight same direction and turning opposite direction were the most frequently occurring trajectory types, accounting for 30.6% and 25.1% of all bicycle-LPV crashes, respectively. Angle crashes (88.5%) were the most frequent bicycle-LPV crash type.

Table 1: Descriptive statistics for bicycle-LPV crashes (selected variables shown only).

Explanatory variables	Injury severity categories			Total
	Fatal and Hospitalised (N=1,188)	Medical treatment (N=1,321)	Minor injury (N=626)	
Crash type				
Angle	1,068	1,176	533	2,777
Rear-end	32	37	24	93
Head-on	8	5	3	16
Sideswipe	80	103	66	249
LPV trajectory				
Straight opposite direction	236	257	110	603
Turning opposite direction	340	312	133	785
Straight right angle	262	274	113	649
Straight same direction	310	419	232	961
Turning same direction	40	59	38	137

3.1 Estimated results of MXL models

Estimation results of the two MXL models (crash type and the trajectory type variable, both including a common set of other variables) are presented in Table 2. The severity category to which each parameter belongs is listed in brackets: [MI] minor injury, [M] medically treated injury, [H/F] hospitalised injury/fatal. Medical treatment is used as the estimation base, by assuming the constant specific to medical treatment is equal to 0.

There was a smaller AIC value for the ‘Trajectory type’ model than the ‘Crash type’ model (6,281 vs. 6,299) and similar restricted log-likelihood values and McFadden’s ρ2 values, thus suggesting no significant differences in model fitness between the two models.

Results of the ‘Crash type’ model showed that only sideswipe crashes were associated with an increased probability (2.3%) of minor injury. The other crash types were not found statistically significant.

The 'Trajectory type' model showed that straight same direction crashes increase the likelihood of minor injury by 5.8%, which is aligned to some extent with the proposed hypothesis that a collision between a LPV moving straight ahead along a roadway and a cyclist will have a higher likelihood of severe injury occurring to the cyclist. However, in contrast to the hypothesis, turning opposite direction crashes increased the likelihood of fatal/hospitalisation injury at intersections by 5.1% in the Trajectory type model. This might be because motorists focus on finding a gap in opposing automobile traffic rather than detecting cyclists (Koustanai et al., 2008), and turn as quickly as they can when gaps are small without considering the possibility of an oncoming cyclist. The results confirm the hypothesis that straight right angle crashes increase (4.2%) the likelihood of fatal/hospitalisation injury in the Trajectory type model.

Table 2: MXL severity model results (selected variables shown only).

	Crash type model		**Trajectory type model**	
Variables	Coefficients (P-value)	Elasticity (%)	Coefficients (P-value)	Elasticity (%)
Dependent variable				
Constant [Fatal/Hospitalised]	-0.844 (0.007)		-0.043(0.481)	
Constant [Minor injury]	-0.085 (0.732)		1.260 (0.000)	
Crash type				
Sideswipe [MI]	0.449 (0.016)	2.32	N/A	
Trajectory type				
Turning opposite direction [F/H]	N/A		0.503 (0.001)	5.10
Straight right angle [F/H]	N/A		0.497 (0.004)	4.24
Straight same direction [MI]	N/A		0.289 (0.049)	5.80
Model statistics				
Log-likelihood	-3,127.5		-3110.5	
Restricted log-likelihood	-3,403.5		-3403.5	
McFadden, ρ2	0.09		0.09	

N/A: variable was not present in the model

4 CONCLUSIONS

The results demonstrate that trajectory type can provide additional information regarding the crash mechanism for bicycle-motor vehicle at intersections, compared to the traditional use of crash types in such analyses.

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Validation of a VR cycling simulation in terms of perceived criticality and experience of presence

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Keywords: Cycling Simulator, Perceived Safety in Cycling, Virtual Reality, Automated Vehicles.

1 INTRODUCTION

Cycling offers many benefits, such as reducing traffic congestion, lower emissions and health benefits [1]. To further promote cycling, the cyclists' perceived safety needs to be addressed [2]. In this context, automated vehicles offer high potential for designing safe and comfortable interactions with cyclists in the future [3]. A key parameter in these interactions constitutes the proximity of vehicles passing cyclists to avoid causing discomfort [4]. To evaluate specific scenarios with varying proximity, cycling simulators provide a safe and standardized environment for traffic safety research. Therefore, there are numerous efforts to implement cycling simulators for use in research [5]. However, it is important to verify the simulator validity to ensure the generalizability of results [6]. In this work, an implementation of a virtual reality (VR) cycling simulation is presented and it is aimed to investigate the simulator validity in terms of perceived criticality in traffic conflict scenarios as well as the participants' experience of presence within the VR cycling simulation.

2 METHOD

2.1 Experimental Design

The study is implemented as a 3 x 4 within-subjects design and consists of three conflict scenarios between a cyclist and vehicle, each with four different levels of potentially critical outcome: non-critical (baseline condition) as well as low, moderate and high potential of a critical outcome. As dependent variable, the perceived criticality within the conflict scenarios is assessed.

2.2 Material

2.2.1 Cycling Simulation

The open source project LoopAR [7] is used as basis for the VR cycling simulation. Originally, this virtual reality environment of a city was developed in the Unity 3D game engine and used for studies on automated driving from the passenger perspective (e.g., takeover requests) [7]. The simulation was modified to provide a naturalistic impression of a bike ride, including the cyclist's perspective when sitting on a bike as well as the moving bicycle wheel, the handlebar and the cyclist's hands in the foreground. In addition, three different perspectives of the cyclist were implemented, i.e. to the front, to the right and to the left. Using a static bicycle, this setup allows laboratory studies in front of three monitors. Alternatively, the VR cycling scenarios with only a frontal perspective and no static bicycle can be used as video files in online studies. The latter is applied in the present work.

2.2.2 Conflict Scenarios

In all conflict scenarios, the cyclist has priority. However, the vehicle crosses the cyclist's trajectory in front of him with varying proximity. The three conflict scenarios are depicted in Figure 1: In the first scenario (see Fig. 1, left), the cyclist approaches to an intersection while a vehicle from the left closely crosses the cyclist's trajectory. In the second scenario (see Fig. 1, middle), the cyclist passes vehicles standing on the parking lane while one of them suddenly leaves the parking lot. In the third scenario (see Fig. 1, right), the cyclist overtakes waiting cars using the bike lane while the first vehicle suddenly accelerates and turns right.
To systematically vary the proximity in the three scenarios, the initially attempted post encroachment time (IAPT) is used [8]. This prospective measure is based on the timespan between the leaving of the first and arrival of the second road user at a conflict point, if no speed adjustments are initiated by the road users. A lower IAPT is related to a higher potential for a critical outcome of the scenario while the vehicle crosses the cyclist's trajectory with lower proximity. In this study, scenarios with low potential for a critical outcome are designed with an IAPT of 3 seconds, a moderate potential for a critical outcome with an IAPT of 2 seconds and a high potential for a critical outcome with an IAPT of 1 second.

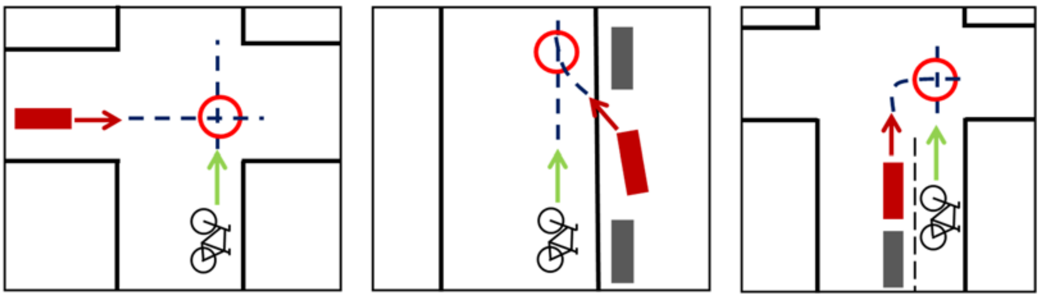

Figure 1: Three conflict scenarios between cyclist (green) and vehicle (red).

2.2.3 Questionnaires

Sociodemographic variables are asked including the cycling experience and frequency of bike use. Additionally, sensation seeking [9] as well as affinity for technology interaction [10] are rated. For measuring the perceived criticality within the conflict scenarios, the Scale for criticality assessment of driving and traffic situations [11] is used. The scale ranges from 0 (~ not critical at all) to 10 (~ most critical). Further, the participants' experience of presence in the cycling simulation is measured. For this, the Igroup Presence Questionnaire [12] is used, containing 14 questions regarding spatial presence, involvement and experienced realism. The scale ranges from -3 to +3 with different verbal anchors.

2.3 Procedure

The online study is conducted using jsPsych [13] and starts with a sociodemographic questionnaire. Then, the videos with the conflict scenarios are presented in random order. Each video has a length of approximately 30 seconds, beginning with an urban bike ride and ending with a black screen shortly after the onset of the conflict scenario. Thus, it is not clear to the participants how the scenario ends, i.e., whether the vehicle still yield to the cyclist or not. This should focus on the potential criticality and avoid changes of mind after showing the successful resolution of the scenario [14]. After each video, the perceived criticality is assessed. At the end of the study session, the experience of presence within the VR cycling simulation is rated.

3 RESULTS & DISCUSSION

The study results are pending and will be presented at the conference. The analysis will include whether the perceived criticality varies according to the different IAPT levels within the three conflict scenarios. Furthermore, individual differences, such as regarding cycling experience and sensation seeking, will be considered. In addition, the VR cycling simulation will be evaluated based on the ratings for the experience of presence. The results will provide first indications on the simulator validity, especially regarding the perceived criticality in traffic conflict scenarios. This is important for future studies investigating the interaction between automated vehicles and cyclists to design safe and comfortable driving maneuvers. Further, advantages and disadvantages of the presented implementation of a VR cycling simulation will be discussed.

4 ACKNOWLEDGEMENT

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E-scooter accidents and risk factors – survey results from users of rental e-scooters in Norway 2021

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1 INTRODUCTION

After rental services of e-scooters started in Norway in 2019, they became very popular and widespread, which also led to many accidents and injuries. This was systematically registered and published by the Oslo Emergency Ward every month and the figures showed a clear tendency for the accident figures to follow the scope of use, with higher figures in the summer. There is also an increase in accidents and injuries from 2019 to 2020, and on to 2021 [1, 2].

To investigate further about risk factors involved when using e-scooters, we conducted a comprehensive survey among e-scooter users in Norway.

2 DATA AND METHOD

The survey was carried out among registered users with e-scooter rental companies in Norway in October-November 2021. Respondents were contacted and provided with the link to the questionnaire by the rental company they used. In total 2585 respondents answered the questionnaire. In total 474 respondents said they had had an accident (crash or fall) with an e-scooter (any time) and 225 of those said they had sustained an injury in such an accident.

Data was analysed by use of logit models, and risky behaviour was entered as independent variables as indexes covering three groups of risky behaviour; a) riding under the influence, b) distraction (smart phone) and c) non-compliance with the traffic rules. Gender, age and mileage were also entered as independent variables in the models. Two sets of models were computed; a) with accident as the dependent variable and b) with injury (given an accident) as the dependent variable.

3 RESULTS

The distribution of self-reported accidents and injuries by gender and age largely corresponds with the figures registered in the emergency room. Men have more accidents and injuries than women, and young people have more injuries than older people. Results from the regression models show that the gender difference in accident involvement is due to men using electric scooters more than women, so when controlling for the extent of use, there is no gender difference in accident involvement. Young people are more likely to have accidents than older groups, also when controlling for how much they use e-scooters.

There are statistically significant effects of the risk indexes; i.e. those behaving risky according to the indexes, have higher odds of having had an accident. Thus, the main reason why younger riders are more at risk is that they engage more in risky behaviour when riding e-scooters.

When personal injury is used as the dependent variable, the results show that women are more at risk of sustaining an injury than men. The same is the case for those above 55 years of age compared to younger riders. There is also a tendency that those using e-scooters in the larger cities are more at risk of sustaining injuries given an accident, than riders in small cities and outside cities.

4 CONCLUSIONS

Young riders are overrepresented among users of e-scooters and among those experiencing accidents with these vehicles. Men use e-scooters more than women, and thus constitutes a larger share of accident victims, giving similar risk levels for men and women.

This study clearly shows that risk factors such as riding under the influence, being distracted by smart phone and not following the traffic rules, increase the risk of having an accident. Young riders are overrepresented among those behaving in risky ways while riding, making them more at risk as e-scooter riders. Women and elderly riders are most at risk of sustaining injuries when a crash occurs.

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Measuring the Mechanical Properties of Bicycle Tyres to Help Predict and Minimize Wobble for Enhanced Safety

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Keywords: Bicycle, Tyres, Measurement, Wobble, Shimmy.

1 INTRODUCTION

Wobble, also known as speed wobble or shimmy, and the hazard it can cause to cyclists, is a well-known behavior of some bicycles. It is a relatively high-frequency oscillation, 4–10 Hz, of the front fork and wheel assembly about the steering axis, and it can result in loss of control if left unaddressed.

The importance of tyre mechanical properties, specifically cornering stiffness, to the wobble motion of bicycles has been shown.[1][2] Some tyres can make a bicycle more likely to wobble, while others can make the same bicycle less likely to wobble.

There are only a few facilities in the world, however, capable of measuring these properties of bicycle tyres, and facilities for testing motorcycle and automobile tyres are not designed to work with bicycle wheels and/or are prohibitively expensive to use.

We introduce and characterize an inexpensive, table-top device for measuring the necessary mechanical properties of bicycle tyres.

Figure 1: An image of an early prototype at the University of Wisconsin-Milwaukee.

2 GENERAL DESCRIPTION

This table-top tyre property measuring device features:

- a rigid-slat treadmill that avoids all issues with curvature in the contact patch caused by rotating disks and drums and only needs a flat surface big enough for a bicycle tyre contact patch.
- compatibility with most bicycle hubs and any rim, so a tyre can be tested on any particular wheel and on a variety of wheels.
- the capability of measuring both cornering stiffness and camber stiffness, as well as the associated moments, referred to by some authors as self-aligning and twisting torques.

3 RESULTS

Figures 2 and 3 below show example raw and summary cornering stiffness and camber stiffness data.[3]

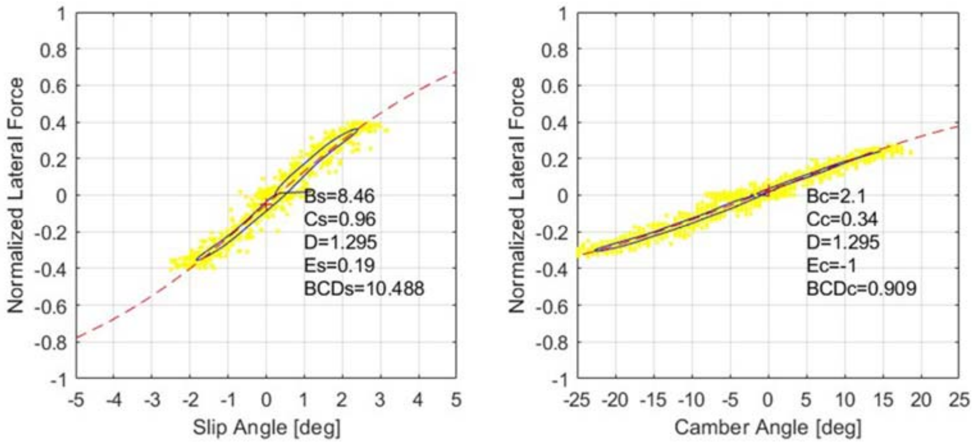

Figure 2: Example stiffness raw data, smoothed line, and fit curves for a particular tyre, rim, vertical load, and inflation pressure.

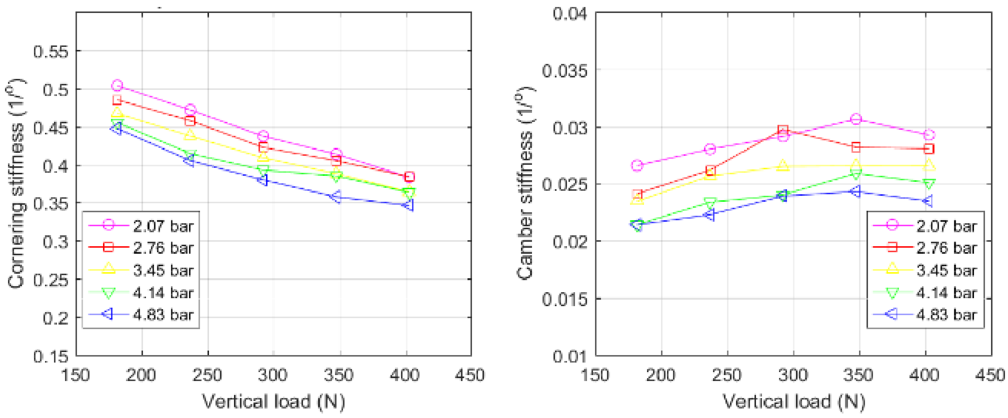

Figure 3: Example summary data showing how stiffness varies with inflation pressure and vertical load.

4 TYRE STIFFNESS EFFECT ON WOBBLE

Sharp's motorcycle equations of motion [4] can be used to show the effect that changes in tyre stiffness can have on the wobble mode if tyres are added to Meijaard's benchmark bicycle [5]. In figure 4, decreasing

Sharp's front tyre stiffness parameter from 628 lb/rad (2793.5 N/rad) to 504 lb/rad (2242 N/rad) causes the wobble mode to become unstable at about 9.5 m/s (34 km/h).

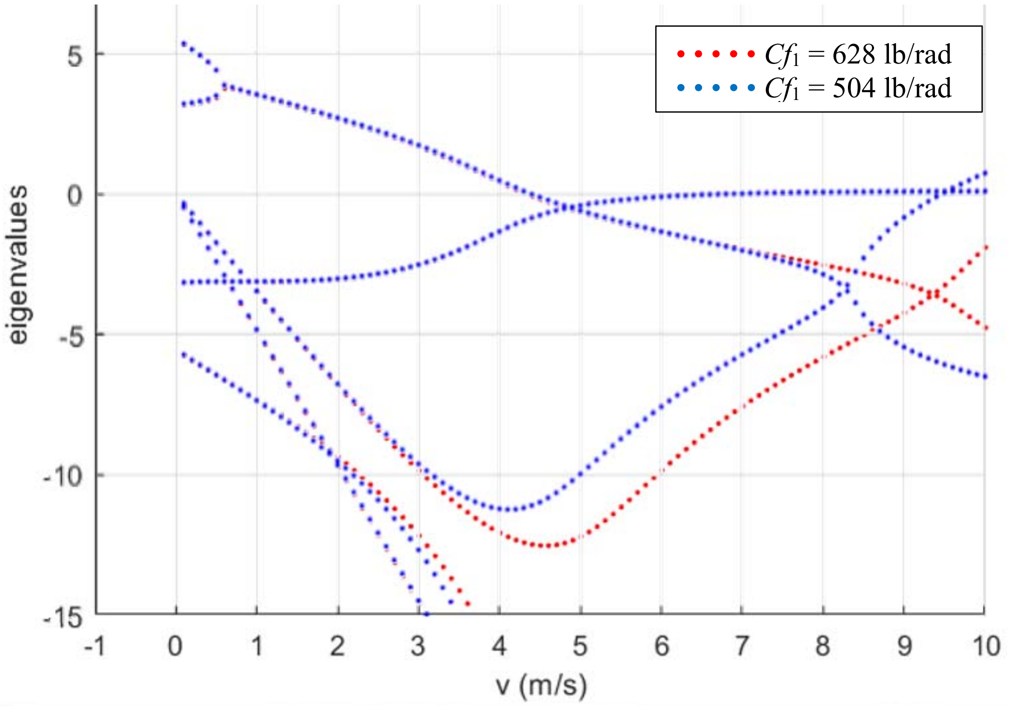

Figure 4: Stability eigenvalues for Meijaard's Benchmark Bicycle with Sharp's motorcycle tyres.

5 EXPECTED RESULTS

We will present the mechanical design features of the new tyre testing machine and how they relate to the resulting accuracy and precision of the tyre stiffness, force, and moment estimates. Cornering and camber stiffness for widely used city bike tyres will be provided and predictions of wobble for consumer bicycles that are known to exhibit the dangerous behavior.

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The effects of a steer assist system on bicycle postural control in real-life safety challenges

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Keywords: steer-assist, aging, bicycle, safety, postural control, assistive technology.

1 INTRODUCTION

With aging, the sensory, motor, and central nervous system deficiencies lead to inadequate bicycle postural control in older cyclists [1]. Similarly, variety in riding skills leads to different bicycle postural control strategies. Cycling seems to be an automated task but keeping the bicycle stable at low speed, pedaling, and steering requires continuous physical and cognitive effort, and in long term may lead to fatigue induced by steering and stabilizing the e-bike at low forward speeds especially in older cyclists [2]. E-bikes enables riders to cycle for longer duration and distance by reducing the physical fatigue [3]. There is an increasing societal interest in electric bicycles where in 2021, 26.73 billion US dollars worldwide have been invested on e-bikes and by 2027 this global market size will increase to 53.53 billion US dollars (Statista). However, with increased numbers of e-bikes, bicycle accidents due to inadequate steering and balance control by older cyclists have increased [4], which suggests needs for extra safety measures to maintain balance on a bicycle for challenging situation such as facing undesired disturbances or low forward speeds.

We developed a prototype steering assist [5] which aims to increase safety and improve the user experience, by reducing the steering effort and enhancing the bicycle postural control (rider-bike balance control). We investigated the potential effectiveness of the steering assist technology in real life challenging situations. Our present study should be considered exploratory research to find the potential effectiveness of the steering assist technology in improving the user experience and safety compared to a non-assistive e-bike. The improved bicycle postural control is validated by smaller range, variability, and rate of steering and roll trajectories when the rider is subjected to an unwanted disturbance. Improved bicycle postural control is expected based on the reduced need for compensatory behavior in the presence of assistive technology. Decreased steering effort is expected due to reduced demand for acute steering control in the anticipatory control strategy.

2 METHODS

This study focused on the effects of steer assist technology on bicycle postural control at low speed, mimicking the condition when an unwanted disturbance applies to the rider or bike and causes instability, such as when you hit a bump in the road or front rack cargo pulls the steer in an undesired direction. These pilot results are part of a larger data set to be collected from 40 participants (20 old and 20 young). The ethical board of the Delft University of Technology (The Netherlands) approved the research ethics. One healthy male participant (age 27) participated in this pilot study. The participant had no fall history during cycling over the last year. The participant first cycled for 5 minutes to get familiarized with the steer assist system to reduce the habituation effect throughout the experiment. Afterward, he performed four trials in total on the steer assist e-bike on eco mode. We instructed the participant to cycle in a straight line with a self-selected speed. We induced 1.2 Nm steer torque perturbation half a second after the forward speed reached 1.5 m/s, with the presence (x2 trials) and absence (x2 trials) of the steer assist system on the e-bike.

We have selected the data segment where the rider accelerated at the start point of the track and stopped after deceleration at the end of the track based on the data collected from a wheel speed sensor. We used an inertial measurement unit sensor on the rear frame and the steering angle sensor on the steering column and calculated the roll rate and angle and steering rate and angle. In the selected part of the time-series data, we calculated the standard deviation of the steering and roll angle and rate. Moreover, we calculated the range of change in these variables defined as maximum minus minimum values in a selected segment of the time-series data. Finally, we calculated the average of two trial repetitions per condition.

2.1 Results

The results are shown in Figure 1 and Table 1. In Figure 1, we report the time-series data of roll and steer trajectories for one representative trial per condition. In Table 1, we report the average data of two trials per condition. Note that the large range of the steering angle in the trial without the steering assist (Figure 1, right panel) is due to the large steering angle at the end of the trial.

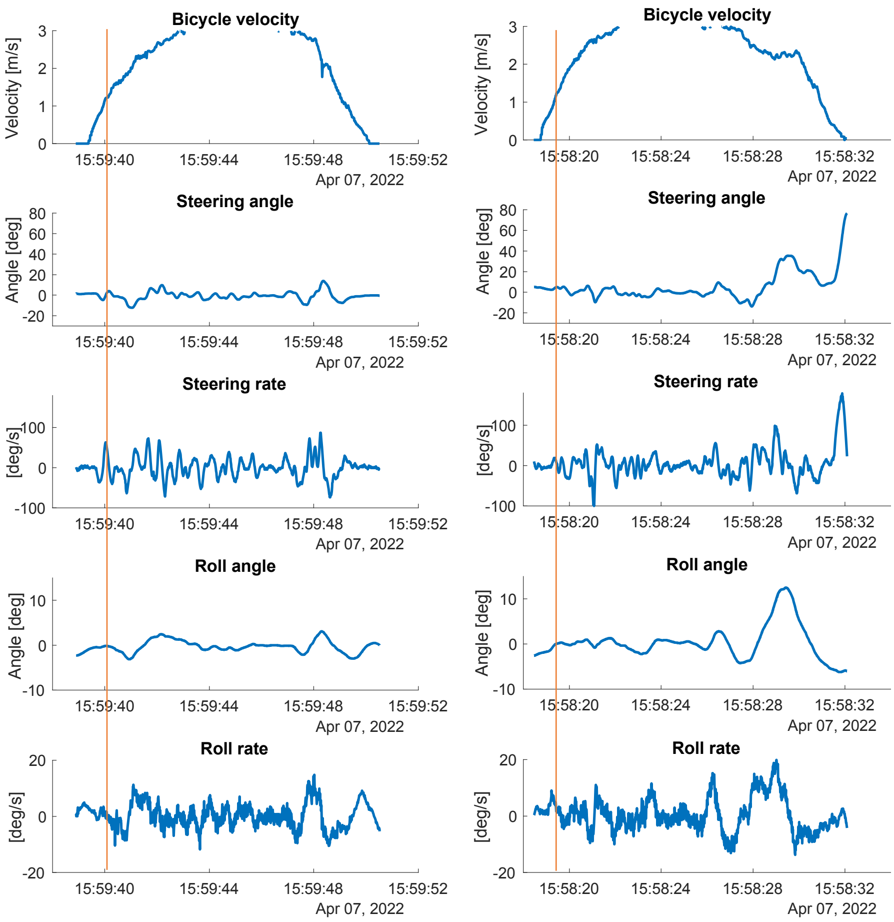

Figure 1: Time-series data in the presence of perturbation; in the left panel, the steering assist is activated (one random trial with the steer assist condition reported in the abstract); in the right panel, the steering assist is deactivated (one random trial of without the steer assist condition reported in the abstract). The orange vertical line is when the disturbance is applied. data in presence of perturbation; in left panel the steer assist is activated (one random trial of with the steer assist condition reported in the abstract), in the right panel the steer assist is deactivated (one random trial of without the steer assist condition reported in the abstract). The orange vertical line is when the disturbance was applied.

Table 1: We present the average standard deviation (SD) and range of trajectories of two trials in the table.

Variables	Disturbance with steer-assist	Disturbance without steer-assist
SD Steer angle [deg]	7.3	15.875
SD Roll angle [deg]	1.991	3.884
SD Steer rate [deg/s]	26.55	34.515
SD Roll rate [deg/s]	4.6066	6.3942
Range of Steer angle [deg]	42.65	86.1
Range of Roll angle [deg]	8.3079	17.9336
Range of Steer rate [deg/s]	181	249
Range of Roll rate [deg/s]	27.015	38.0444

3 CONCLUSIONS

A bicycle, by nature, is unstable at low forward speed. Applying an external disturbance can excite the instability. We aimed to increase the stability at low forward speed by a steer assist technology. We evaluated the system's effectiveness in a challenging condition mimicking the real-life disturbances applying on the rider and bicycle. Our pilot data showed promising results when riders face perturbation while riding in a straight line at low forward speed.

The results showed that the amount of steering was reduced when using a steer assist system. Moreover, the roll parameters, including roll rate which influence bicycle postural control, were reduced when using a steer assist system. Our results suggest that the steer assist system has the potential to increase safety in challenging conditions and improve the user experience. Further investigation is required to confirm our pilot results.

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Assessing cycling skills in Switzerland

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Keywords: cycling safety, accident analysis, expert interviews, accident prevention

1 INTRODUCTION

For many people, safety concerns are a major barrier to ride a bicycle. Indeed, cyclists bear a higher risk than most other types of road users. Parallel to the increase in cycling an increase in accidents involving cyclists can be observed. In Zurich, the number of accidents involving cyclists increased from 250 to 450 between 2010 and 2019. In the same period, a decrease in the number of accidents involving motorized vehicles and pedestrians was registered.

Improving cycling infrastructure is the most obvious and effective way to increase cycling safety. However, at the same time it is likely that the uptake of cycling can be attributed to a generation 'becoming urban cyclists' [3] and that cycling skills and competences are not aligned with the cycling infrastructure at hand. In parallel, other participants in traffic might not be aware of the presence of cyclists and lack knowledge of specific cycling characteristics (e.g. driving speed, lateral movement at different speeds, acceleration / deceleration, route and lane preferences).

Cycling requires a set of competences that include bodily fitness, steering and balancing skills, and knowledge of local traffic systems [4]. In addition, in many cities, cyclists are expected to perform in the same way as motorists, do not have dedicated infrastructure and are expected to share road space with motorists [3], [5]. These circumstances require more than just balancing skills and knowledge of pedalling and breaking. Rather, cyclists are required to weave and merge with vehicular traffic, pay attention to pedestrians and other cyclists, and navigate at the same time.

This paper sets out to identify skills required by cyclists to navigate safely through an urban environment in Switzerland. We set out to identify situations that might result in accidents and require specific competences. Three study studies were conducted. First, workshops with experts were conducted to identify required cyclists' skills. Second, accident statistics were analysed to determine in which type of situations accidents occur. Finally, a survey was conducted among Swiss cyclists to assess which skills were present and which skills were lacking. The remainder of this extended abstract describes the three studies in some detail and continues with an outlook for the final paper.

2 STUDY 1: EXPERT INTERVIEWS - IDENTIFYING RELEVANT SKILLS

2.1 Methodology, Materials and Sample

To identify cycling skills, focus groups discussions were organized. Nine experts from the fields of traffic planning, bicycle training, driving instruction, traffic safety and traffic instruction were recruited to participate.

Prior to the focus group discussions, an overview of cycling skills was gathered from (1) academic research [6] (2) applied research [7] and (3) directly from experts prior to the discussions. In total, almost 60 cycling skills were identified. Experts were asked to discuss and evaluate this exhaustive set of cycling skills with regard to their ability and relevance to prevent cycling accidents.

2.2 Results

Skills were prioritized on the basis of the evaluation of experts and categorized into higher-level abstract skills, situation-related concrete competencies and practical motor skills. In total 16 cycling skills to prevent accidents were identified. The experts rated higher-level, strategic, skills, such as 'anticipatory cycling', 'identifying risks', and 'keeping alert', as central to avoiding accidents. The following situation-related, concrete competencies were given particularly high priority: dealing with blind spots, mastering roundabouts, recognizing right of way, looking over one's shoulder and maintaining a safe distance from dangers such as parked cars. Practical motor skills, such as being able to respond quickly, use the brakes correctly, and maintain balance, were also rated as highly relevant. Practical motor skills (operational driving skills), such as being able to respond quickly, using brakes correctly and maintaining balance, were also rated as highly relevant.

3 STUDY 2: ACCIDENT STATISTICS: IDENTIFYING RELEVANT SITUATIONS

3.1 Methodology

We set out to analyse reported accidents involving cyclists in Switzerland in the period 2011 - 2021.

3.2 Results

Almost 40% of cycling accidents involves a single object; i.e. do not directly involve other traffic participants. We also see that in the remaining accidents, approximately 40% cyclists are the party at fault, with the remaining accidents being caused by another party. A word of caution is appropriate here: the reporting methodology as well as legal requirements require to define a party at fault.

In most cases, the cause of the accident is attributed to 'priority': 24% of the accidents can be attributed to different types of ignoring priority (excl. traffic lights); another 23% can be specifically attributed to ignoring priority signs (excl. traffic lights).

4 STUDY 3: IDENTIFYING CYCLING SKILLS

4.1 Methodology, Materials and Sample

To assess whether cyclists possessed certain skills a survey was developed. The survey was designed as a two-stage survey. The first stage served as a screening survey to ensure that quota met.. In the second stage of the survey (main survey), participants were asked to state their behaviour in a series of situations.

The first part of the main survey showed participants 6 situations. Participants were asked whether they would look left, right, forward, backwards, whether they would adjust their speed, what their preferred position on the road was and whether they use their cycling bell. The second part showed participants a series of situations where participants were asked to state their preferred position on road in blind spot situations, on a roundabout and when turning left. The third part focused on priority rules. Within the first 3 parts of the survey, situations were randomized between subjects. In total participants were shown 14 situations.

Parallel to the survey experts were asked to fill out the survey. These experts consisted of cycling instructors. To assess whether respondents' behaviour in the different situations was correct, respondents' answers were compared to answers provided by experts. participants were asked to state their behaviour in a series of situations.

4.2 Results

Evaluating specific competences
In this abstract we will highlight the analysis of cycling skills for two situations.

Kompetenz	ExpertInnen	Abweichung
Ich schaue nach hinten	4	47%
Ich schaue weit nach vorne	5	45%
Ich schaue nach rechts	4	43%
Ich schaue nach links	4	37%
Ich gebe ein Handzeichen	4	36%
Ich bin bremsbereit	4	27%

Figure 1 Turning left with priority

Figure 1 depicts the answers for the situation in which a cyclist turns left, but has right of way. Experts consider it important that cyclists look over their shoulder ('Ich schaue nach hinten') and that they look far ahead. Almost 47\% of the survey participants indicated that they might not look over their shoulder.

Kompetenz	ExpertInnen	Abweichung
Ich schaue nach hinten	5	44%
Ich schaue nach links	4	41%
Ich gebe ein Handzeichen	5	41%
Ich bin bremsbereit	4	38%
Ich schaue weit nach vorne	4	36%

Figure 2 Turning left with priority

Figure 2 depicts the answers for the situation in which a cyclist continues straight at a branching, but has to mind turning. Experts consider it important that cyclists look over their shoulder ('Ich schaue nach hinten') and that they glance left. Almost 44% of the survey participants indicated that they might not look over their shoulder.

Evaluating specific situations
When looking at specific situations, it becomes apparent that cyclists not always recognize right-of-way correctly on residential streets (Figure 3) and choose not to use the middle of the lane on roundabouts (Figure 4), as recommended in Switzerland. Cyclists do choose the correct position when turning left and deal with blind spots as recommended by experts.

Figure 3 Right-of-way

Figure 4 Roundabouts

5 CONCLUSION & OUTLOOK

This research has shown that there is potential to further develop cyclists' skills. Rather than focusing on motoric skills or presenting simple situations, we advise that skills should be trained based on more complex situations. These situations include turning, branching, maintaining distance from parked cars and recognising right of way in residential areas.

In addition to the presented analyses, we evaluated differences in answers between age groups, gender and cycling frequency. In the presentation we will discuss the results. Furthermore, we aim to calculate a single score per situation and skill type to be able to assess whether statistically significant differences between groups exist. Finally, we will comment on the differences between the stated subjective safety of survey participants, and the stated safety by experts. We are looking into ways to disseminate the survey further to obtain a broader audience and are especially interested in showing participants a wider range of slightly similar situations to determine whether specific elements in pictures play a role.

The results of this research inform the development of digital cycling training program for adults and have helped to prioritize the contents of such an educational program.

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Personal Light Electric Vehicles – Introduction of a new vehicle class in Germany
From research to legislation and implementation into road traffic

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Keywords: Personal Light Electric Vehicles in Germany, research, legal requirements, traffic safety, accident analysis.

1 INTRODUCTION

Self-balancing vehicles or those without any seat so called Personal Light Electric Vehicles (PLEV) are excluded from the scope of the Type Approval Regulation (EU) No. 168/2013 for two- or three-wheel vehicles and quadricycles (category L vehicles) thus they have to be regulated on national level since 2016. Furthermore, at that time a definition of micromobility devices was missing - and therefore different national categories with detached requirements were established. In 2019 SAE International published the J3194™ [1] for the classification of powered micromobility vehicles.

A fundamental research project [2] undertaken by the German Federal Highway Research Institute provided recommendations to integrate PLEV with respect to traffic safety into the existing road traffic. Subsequently, the legislative frame called Personal light electric vehicles regulation [3] enforces the approval of PLEV and safe usage in Germany as well as administrative offences. Behavioural rules, technical and safety requirements characterize the PLEV regulation.

In a next step, PLEVs market introduction with respect to traffic safety is evaluated in a current project with different aspects e.g. a market dissemination, user analysis and user behaviour, traffic surveillance and accident analysis.

2 PRELIMINARY RESEARCH

The Federal Ministry for Digital and Transport commissioned the Federal Highway Research Institute to conduct a research study [2] with the aim to establish recommendations for PLEV as a new vehicle classification. These recommendations incorporated technical requirements of vehicle safety as well as the appropriate traffic area (walkway / cycle path / road). In the project different studies were carried out to address the research question: Statements about the driving dynamics (e.g. target braking, maximum deceleration, lane-change track, handling at low speed, etc.) were derived from test rides on a course. Passive safety issues as protective equipment (helmet) and edge protection were considered. Furthermore, a volunteer study assessed user behaviour and user acceptance.
Additionally, it was important to identify the applicable traffic area (see Figure 1) to prevent possible conflict potential with other road users. As a focal point the vehicle dynamic stability was examined on a special designed test track.

Figure 1: Research on the choice of infrastructure and dynamic stability tests.

3 OVERVIEW OF THE LEGAL REGULATION

Motorized vehicles are generally subject to authorisation for use on public roads in Germany. At least they need to have a national type approval. Due to that, vehicles are grouped into appropriate vehicle categories. On 15th of June 2019, the Personal Light Electric Vehicles Regulation [3] went into force with scope on PLEV: This micromobility devices can be for instance electronic kick scooters (e-scooters) or self-balancing vehicles. To be more precise: In Germany this category subsumes electrically powered motor vehicles with a maximum design speed not exceeding 20 km/h without a seat or a self-balancing vehicle with or without a seat. Furthermore, a handlebar, lighting and light-signalling devices, two independent brakes and a bell are mandatory [3]. Other vehicles which do not meet these requirements might be categorized as micromobility devices such as hoverboards or electric skateboards must not be used in public traffic, as they are not regulated.

Other European countries have their own licensing requirements - in some cases PLEV are treated as bicycles or as a motorized vehicle. Corresponding technical and behaviour aspects have to be followed. Furthermore, the European Standard EN 17128 [4] describes the state of the art in terms of requirements and test methods for PLEV.

4 FINDINGS FROM REAL ROAD TRAFFIC

With entry into force of the PLEV Regulation in Germany, there has been a rapid market ramp-up of those vehicles mainly due to the rental systems with e-scooters in major German cities. On top to the shared vehicles the private owned enter the road traffic. Begin of April 2022, 171 different PLEV models were approved and gained a national type-approval by the German Federal Motor Transport Authority (KBA) [5]. PLEV can be considered suitable as a part of traffic transformation process away from the classic transport modes. But it has to be stated, that new challenge occurs by using or misusing PLEV (see Figure 2). For example, a huge everyday issue is placing those vehicles in unsuitable places often as an obstacle for others. As these small and light vehicles are designed for personal transport and not for the transportation of passengers a potentially dangerous situation can occur. Furthermore, national and international research often report single-vehicle accidents as the majority of crashes [6], often in combination with alcohol [6] [7].
A medical study from Hamburg analysed head and facial injuries and reported a relatively large number of injured patients with alcohol intoxication among the e-scooter users [8].
Currently a research project [6] is ongoing for a detail analyse of the impact of PLEV with regard to road safety. As the study is still in progress a first overview will be given. Beyond that reference is made here to further material already published by the Federal Statistical Office [7]. For the year 2020 the Federal Statistical Office describes a total of 264,499 accidents involving personal injury in Germany [8]. Of these, 91,533 were accidents involving bicycles (incl. pedelecs) and 2,155 accidents involving PLEV. In these PLEV accidents, 2,297 individuals were injured of whom 5 died and 387 were seriously injured. One third (31.5 %) of all e-scooter users involved in accidents were under 25 years of age, most frequent cause of accidents was alcohol influence with a share of 19.7 % [7].
A European Topic Guide released by Civitas Elevate [10] focuses on the safety of PLEV and other micromobility devices by giving planning recommendations and best practice examples e.g. on infrastructure, behavioural aspects and facets for regulation.
In Germany as well as in other European countries traffic detractions do occur due to misuse of PLEV as well as conflicts with other (motorised) traffic users often in combination with infrastructure issues [11].

Figure 2: Misuse of PLEV.

5 CONCLUSIONS

PLEV were integrated in road traffic in Germany in 2019 with corresponding legislative rules. Beforehand a scientific study created the basis for this legal regulation (Personal Light Electric Vehicles-Regulation). Initial experience show that these vehicles of a new category have arrived on the roads and new issues emerged (e.g. wrong parking / unsuitable placing) and preliminary findings on accidents have been collected. A large proportion of the problems are due to misconduct by the PLEV user. In an ongoing fundamental research project, the impact of PLEV with respect to traffic safety in Germany is currently evaluated and European aspects regarding the traffic safety of PLEV are elaborated.

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A STUDY ON RIDERS' BEHAVIOR AND SAFETY PERCEPTION OF BICYCLE WITH A CHILD SEATING DEVICE

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Keywords: child seating devices, falling, safety perception

1 BACKGROUND AND OBJECTIVES

The number of bicycles with infants is rapidly increasing due to the revision of the Road Traffic Law in 2009 and the spread of electrically power assisted bicycles in recent years. The users of electrically power assisted bicycles are mainly the elderly and the child-rearing generation, and bicycles that allow children to ride along are particularly effective tools for improving the efficiency and health of the child-rearing generation. However, the reckless riding of bicycles by parents is often overlooked because they have no other means of transportation. Therefore, we conducted a questionnaire survey of parents who transport their children to and from nursery schools by bicycle to understand the actual situation of bicycle use and the state of awareness of the rules.

2 REVIEW OF PRVIOUS STUDIES

There have been several studies on bicycles for infants and toddlers, focusing on their functions as a means of transportation, such as clarifying the acceptability of users to a new riding space and the effects on outing behavior during child rearing. The vibration characteristics of bicycles for two infants have also been studied in pursuit of structural functions.

However, there is no research that focuses on the details of falls that are considered to be a problem when using bicycles for infants, the state of awareness of the rules, and the relationship between the structure of bicycles and dangerous events, including bicycles with two infants, which were officially approved by the revision of the Road Traffic Law in 2009. In this study, we conducted a survey on the actual conditions of bicycle use and users' awareness of safety (awareness of rules and interest), focusing on the type of bicycle and seat position of bicycles for infants.

3 METHODOLOGIES

The survey was conducted in Setagaya Ward, Tokyo, which had the highest number of children on waiting lists in the 2017 survey. The reason for this is that in areas with a large number of children on waiting lists, infants are placed in day-care centers that have vacancies regardless of the area in which they live. We distributed questionnaires to parents who use bicycles among the users of day-care centers in each area (especially those that accept many infants aged 3-5). The survey period was from November to December 2018, and the number of valid responses to the questionnaire was 152.

4 RESULTS

The survey was conducted in Setagaya Ward, Tokyo, which had the highest number of children on waiting lists in the 2017 survey. The reason for this is that in areas with a large number of children on waiting lists, infants are placed in day-care centers that have vacancies regardless of the area in which they live. We distributed questionnaires to parents who use bicycles among the users of day-care centers in each area (especially those that accept many infants aged 3-5). The survey period was from November to December 2018, and the number of valid responses to the questionnaire was 152.

4.1 Types of Bicycles

The respondents were asked about their views on bicycle use, i.e., means of transportation in rainy weather and location of bicycle traffic. As for the means of transportation in rainy weather, an overwhelming number of 119 parents answered that they would use bicycles even in rainy weather. As for the position of bicyclists, the average percentage of parents who use the roadway on roads with sidewalks while carrying their children on their bicycles was about 45.1%, while the average percentage of parents who use the roadway when not carrying their children was about 53.6%.

4.2 Falling

When asked about their experiences of falling while using bicycles with infants, 90 (about 59%) of the respondents had fallen. Only 7 parents (about 5%) had experienced an accident, but 61 parents (about 40%) had experienced a near-miss, indicating that many parents had experienced dangerous events. Figure 1 shows the breakdown of the locations of the falls, and about half of them were on the road, indicating that there is a risk of serious accidents. In addition, about 40% of the parents did not respond to the questionnaire, suggesting that they have little impression of falls and do not take them seriously.
Figure-2 shows the number of fall experiences by the position of the infant seat. Bicycles with infant seats installed only in the front were excluded from the analysis because they were very few, but when comparing bicycles with infant seats installed only in the back and bicycles with infant seats installed in both the front and back, it was found that bicycles with infant seats installed in both the front and back had more fall experiences ($\chi2=4.20$, df=1, $p=0.04 < 0.05$).

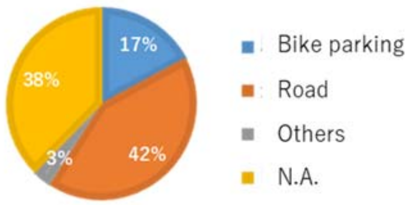

Figure 1: Places where the respondents felt on their bicycles (n=90)

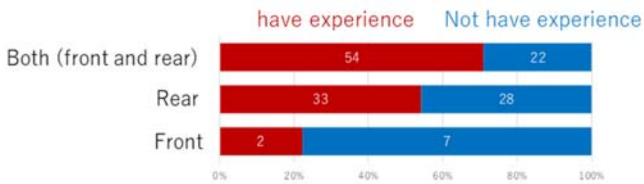

Figure 2: Relationship between experiments of falling on bicycles and positions of seats for children (n=152)

4.3 Safety Perceptions

When the respondents were asked about the rules for riding a bicycle, the percentage of correct answers was as follows.
- In principle, you should ride on the road even if you are carrying a child: 127 respondents, 69% of correct answers
- Only infants under 6 years old can ride in a car: 126 respondents, 56% of correct answers)
- Slow down on the sidewalk: 128 respondents, 91% of correct answers
- Keep to the side of the road when on the sidewalk: 124 respondents, 28% of correct answers
- Drive on the left side of the road, even in the roadside zone: 127 respondents, 90% of correct answers
- Two-step right turn: 124 respondents, 73% of correct answers
- It is not prohibited to go beyond the arrow-shaped lanes (Figure.4 (d)): 125 respondents, 17% of correct answers

- It is not prohibited to go out of the pictogram (Figure.3 (c)): 122 respondents, 56% of correct answers)

It was found that most of the respondents thought that passing on the sidewalk was acceptable when carrying a child, but the percentage of correct answers was also low for the regulations on the number of children who can ride with the driver and the position of the driver on the sidewalk. However, the percentage of correct answers was also low for the regulations on the children who can ride with the driver and the position of the driver on the sidewalk. In addition, there was a tendency to drive on the roadway so as not to go over the arrow feathers, and it was found that it may be difficult for car drivers to predict when overtaking parked cars or when the driver loses balance. These results suggest that safety education for parents is necessary.

Figure 3: Typical dedicated bicycle traffic lanes in Tokyo

5 CONCLUSIONS

This paper reports some of the results of a survey on the use of bicycles for infants and young children, which play a major role in considering the use of bicycles by a wide range of people, and on the users' awareness of safety.

The results showed that more than half of the infant bicyclists had fallen over, as has already been reported, and that many of them had fallen over on the road, which could lead to a serious accident if they made a mistake. The fact that many of the respondents did not answer the question about the location of the fall suggests that they may not remember the fall very well and may not be aware of the danger. In addition, it was found that most of the falls occurred on bicycles with both front and rear seats, which may be due to the weight and difficulty of balancing.

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Bicyclist Head Impact Locations Based on the German In-Depth Accident Study

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Keywords: impact location, head, face, helmet coverage.

1 INTRODUCTION

Head and facial injuries constitute a substantial portion of bicyclist injuries [1]. Helmets reduce bicyclists' head and facial injuries, but not to the same extent for all injury types and locations [2]. Current safety standards for bicycle helmets around the world, including EN1078 (Europe), CPSC 16 CFR 1203 (United States), JIS T 8134 (Japan), AS/NZS 2063 (Australia and New Zealand) and GB 24429 (China), prescribe a standard test line or area for impact attenuation assessment that has limited coverage to head and face. The middle and lower part of the face, which are not protected by most existing helmet designs, are susceptible to soft tissue injuries, fractures and mandibular loading that can cause diffuse brain injury and basilar skull fracture. This study aims to quantify bicyclist head impact locations based on the German In-Depth Accident Study (GIDAS). Knowing which part of the head is impacted most frequently can inform future test method development and helmet designs beyond existing standards requirement.

2 METHODS

To identify head impact locations from injury data, we adopted a similar approach as previous studies [3-4] that collected and analysed locations of external soft tissue injuries on the face and head. Examples of external soft tissue injuries are skin laceration, avulsion, and contusion. These injuries are caused by contact phenomena and hence focal effects of an impact.

For this analysis of injury data from GIDAS we queried the database (January 2022 release) with the following criteria.

General inclusion criteria:

- Fully reconstructed cases from 2010 onwards (all possible information is available and plausibility checks were applied).
- Unhelmeted riders of bicycles and e-bicycles.
- Excluded are pillion riders and run-over cases.

That yielded a number of 5327 bicyclists, with 32.7% involved in single bicycle crashes and 65.4% involved in crashes with two participants.

Injury inclusion criteria:

- The injury must be coded as either AIS body region "face" or "head" (all severities 1-6 were considered).
- Soft tissue injuries were included by the AIS subgroupings
    - Face: Whole Area: Skin/subcutaneous/muscle and
    - Head: Whole Area: Scalp.

That gave 3115 injuries, with a proportion of 99.2% AIS1 and 0.8% AIS2 injuries.

Looking at different variables in GIDAS that could contain injury location information, three variables were chosen to screen injuries: the injury codes according to the 2015 version of the Abbreviated Injury Scale (AIS), and the GIDAS-own variables "SITZ" and "DIAGNOSE". SITZ is describing the location of an injury, in most cases on the level of an individual aesthetic subunit (e.g., cheek, chin). DIAGNOSE can be translated to "diagnosis" and is a free text variable (in German), usually offering information on "what" and "where" (e.g., scalp abrasion temporal). Each of these variables will show a value in the GIDAS injury records but the extent and quality of the information can vary depending on the type of injury and the information available to the analyst reconstructing the case. It can therefore be beneficial to gather all information from the three variables for an individual injury to extract the desired information. Figure 1 is schematically showing the methodology. The injury records were successively checked for the desired location information. The order, AIS - SITZ - DIAGNOSE, can in many cases reflect the granularity of information (from little to large detail), however also the ease of querying and extracting the information (from easy to hard). Merging the AIS code book to the GIDAS injury records made the use of AIS body regions or subgroupings straightforward. The DIAGNOSE variable was checked with a word search algorithm, e.g., looking for words such as "orbita" or "parietal". In few cases where information from different variables was strongly conflicting, we manually checked supplementary materials in the case files (e.g., hospital record) or disregarded the injury as not locatable.

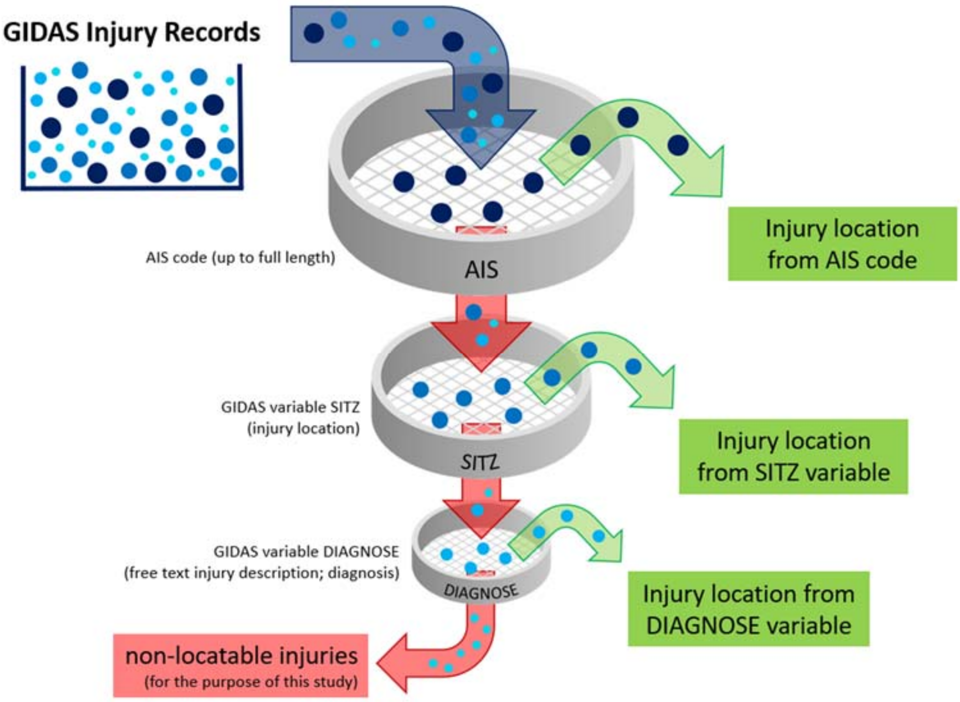

Figure 1: Illustration of methodology for injury localisation based on GIDAS and AIS 2015

3 INITIAL FINDINGS

More AIS1+ soft tissue injuries were located in the face (64.8%) than the head (35.2%). The frequency of soft tissue injury by aesthetic subunits illuminates the forehead being the most frequently impacted region on the face (Figure 2), and the occipital being the most frequently impacted region on the head (Figure 3). However, this picture may differ by different ways of grouping aesthetic subunits. Literature often aggregates the subunits to upper, mid, and lower face. A larger proportion of injuries were not locatable for the scalp/head (47.4%) than for the face (11.2%).

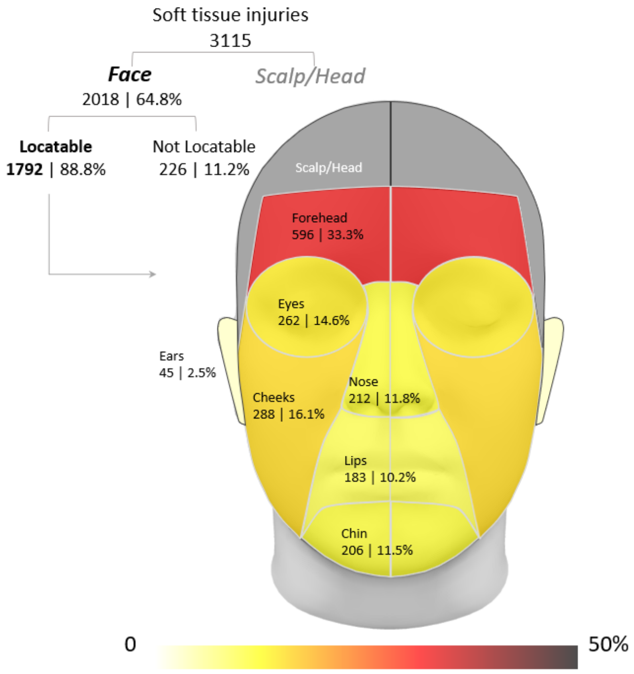

Figure 2: Frequency of soft tissue injury locations on the face. Absolute injury count and percentage are expressed as count | percentage.

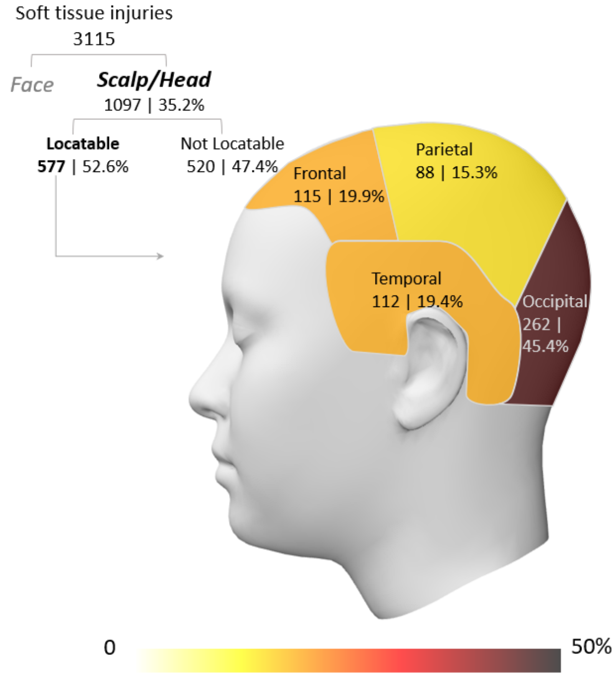

Figure 3: Frequency of soft tissue injury locations on the scalp/head. Absolute injury count and percentage are expressed as count | percentage.

4 DISCUSSION

This study extends our understanding of bicyclist head impact locations by using the most recent and detailed injury data from GIDAS (2022 release) and the most recent AIS 2015 code. We confirm the finding from Malczyk et al. [4] that the face and fronto-temporal region are frequently impacted. We also concur the relative importance of occipital as highlighted by Depreitere et al. [3]. The high frequency of impacts to the face, or generally regions below or close to the test line from safety helmet standards, suggests that a larger test area in the helmet standards is necessary. Helmets can fulfil these protection needs by covering a larger area over the face and head with a permanent structure design or new concepts. To paint a more complete picture for bicyclist head protection, future work will complement this mapping by adding frequency of fractures on skeletal segments of the face and head, and frequency of helmet damage locations of helmeted riders. The relationship between head impact locations and other crash characteristics, and associated more severe injuries that are remote effects of facial impacts (i.e., diffuse axonal injury and basilar skull fracture), will be further explored.

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An in-depth understanding of powered micro-mobility safety issues: a qualitative study

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Keywords: emerging modes, powered micro-mobility, safety, e-bikes, e-scooters.

1 INTRODUCTION

The fast-growing market of powered micro-mobility, including electric bikes (e-bikes) and electric scooters (e-scooters), has introduced a paradigm shift in mobility across the world [1]. These emerging transport modes have frequently been referred to as convenient mobility, having playfulness and transport functions [2]. However, one of the main obstacles to the safe adoption of these transport modes is the safety issues related to their use [3].

Based on the cycling literature, the interaction of vulnerable road users with each other could be classified based on the encounter directions. More specifically, passing is referred to as same-direction encounters, and meeting demonstrates opposite-direction encounters [4]. Experiments and observations have been applied in this research domain for data collection, while interview setups are less conducted to explore users' opinions about their interactions [5]. In this study, we conducted a series of semi-structured interviews and scrutinised e-bike and e-scooter users' safety issues in motorised and non-motorised facilities (e.g. shoulder lanes and sidewalks).

2 METHOD

This study is based on a series of semi-structured interviews. In doing so, we showed interviewees several clips of different transport facilities in Sweden (from the e-bike/e-scooter rider's perspective) and discussed their safety concerns in given situations. Figure 1 represents two examples of discussed situations. These clips contain a variety of interactions of different transport modes (e.g. pedestrians, cyclists, and cars) both in motorised and non-motorised facilities. Subsequently, we explored users' perceived safety based on types of infrastructure, different combinations of road users, and socio-demographic characteristics of users.

(a)

(b)

Figure 1: Examples of given scenarios to the interviewee. The left photo (a) is an example of a shoulder lane, and the right photo(b) is a bike lane.

3 EXPECTED RESULTS AND CONCLUSIONS

The findings of this study contribute to designing dedicated "interaction analysis" experiments by exploring variables associated with the road users' perception of safety. Also, the outcomes provide knowledge for planners and policy-makers on e-bike/e-scooter users' experience with different types of transport facilities and, eventually, how to improve their safety.

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Too close? Investigating the distance between cars and bikes when overtaking with regards to the infrastructure using the OpenBikeSensor and information from OpenStreetMap

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Keywords: OBS, distance measuring, OpenStreetMap, influence of infrastructure.

1 INTRODUCTION

When a vehicle driver overtakes a cyclist, one aspect is very crucial: the distance between vehicle and the bike. The overtaking distance influence the perceived safety as well as the actual safety. Thus, the German traffic rules specify a minimum distance must be kept by 1.5 m between car and bike within the city limits, even two meters outside the city limits. In 2020 a total of 426 cyclists were killed in traffic [1]. The most common cause were right-bending trucks overlooking a cyclist. But close overtaking actions are perceived as one of the most threatening traffic maneuvers to cyclists. The perceived threat respectively the sense of unsafety hinders people even to use their bike for daily errands and commuting. This fact is a big challenge for city and transport planners since cycling is considered to be a very important item for the transition of our mobility system into a more sustainable, safe and city friendly transport system.

Cycling in Germany – and also in many countries in Europe and all over the world – has become more relevant in recent years especially due to the corona pandemic. People have been afraid using public transport and tend to use individual means of transport more intensive. Many cities across Europe supported cycling and pop-up cycle lanes were marked on streets with yellow lines in order to give cyclists more space for safe and comfortable riding. Cities like Brussels, Vienna or Berlin implemented these kinds of "unconventional" infrastructure in 2020 during the first Corona lockdowns [2]. Though, evaluations have shown that the use of these pop-up lanes led to increasing numbers of users on these tracks, these tracks were marked only on a marginal share of the streets in contrast to the whole cycling network of a city.

Other indicators depicting that cycling is advancing are the numbers of sales and the increased willingness to pay for a new bicycle. In Germany, the average price over all sold bicycles in 2021 was about €1,400 EUR [3]. Compared to 2019 (€929 per bike) this is an increase of about 50%. This increase of sales numbers of e-bikes explains this increase. In 2021 about two million e-bikes were sold in Germany in contrast to 2.7 million conventional bikes. The overall market value of sold bikes in Germany was 6.56 billion euros which is an increase by 60% in comparison to 2011 [3].

Nevertheless, a recent Germany-wide survey with over 11,000 participants shows that 91% of the cyclists feel unsafe in German traffic [4]. 69% state that the keeping too little distance between other traffic participants is one of the reasons that people feel unsafe in traffic. The survey also reveals that the feeling of safety would increase by building more bicycle infrastructure (81%) and a clear separation between motorized and non-motorized traffic (62%).

2 INFLUENCE OF INFRASTUCTURE ONTO OVERTAKING DISTANCES

The paper wants to clarify if there are any interdependencies between the *actual overtaking distance* which is kept by drivers when overtaking cyclists and *the infrastructure*. The information is being recorded by using the OpenBikeSensor (OBS). The OBS is an open-source project with the objective to depict how the actual overtaking distances between cars and bikes are in reality [5]. Another open-source project which is not widely known outside Germany is the one meter plus (1m+) project [6]. First own evaluations confirm that the perceived little subjective sense of safety of cyclists when overtaken by a car or a truck is justified since legally prescribed overtaking distances are not observed. The insights are also confirmed by [7] and [8]. The community around the OBS project is steadily growing. Participants of the project want to build awareness for the crucial challenge that traffic rules are not obeyed by overtaking car drivers. Data is being uploaded constantly onto regional allocated (not coordinated) servers. First online visualization kits have been developed (figure 1 and 2).

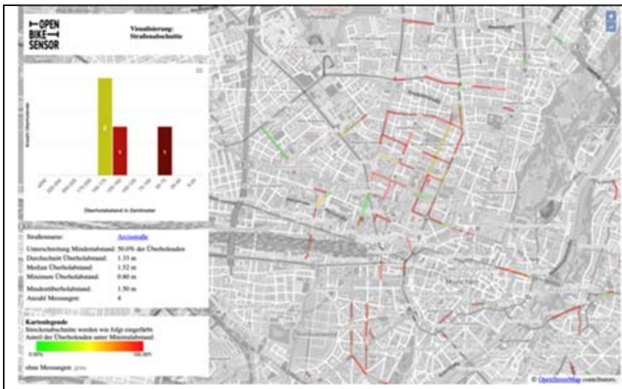

Figure 1: Visualization tools for distance measuring[1].

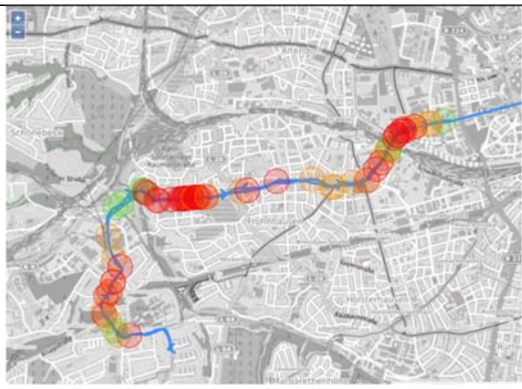

Figure 2: Different visualization[2].

3 RESEARCH DESIGN

The research figured in this paper wants to investigate if and which influence the build environment has on the overtaking distance between cars and bikes. Therefore, the authors are combining data from the OBS project. The research question can be prompted as: *'Are there systematic correlations between overtaking distances and network-side properties of the road space?'*.

The OpenStreetMap project supplies an excellent source of maps deploying roads with a lot of attributes: if there are cycleways on both sides, the road category, number of lanes, maximum speed allowance, name of the road, priority, side of sidewalk, description of smoothness, material of surface, traffic signs, and the width of the road. To answer the research question the authors concentrate on the four attributes road category, speed allowance, surface material, and widths.

Figure 3 exemplarily shows correlations between average speed of the cyclists against the surface material. Since the data collection of the ongoing citizen science project 'Zu nah? Mit Abstand mehr Sicherheit!' (engl.: 'Too close? More Distance, more Safety!') has not been finished at the moment of the creation of this abstract the data used in figure 3 is based on data taken from the Stadtradeln project [9].

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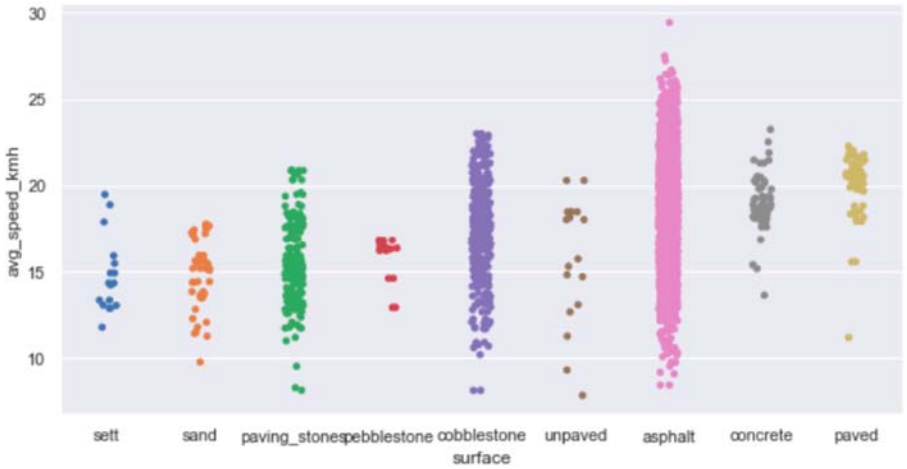

Figure 3: correlation between average cycling speed and type surface. Source: own illustration

4 OUTLOOK

The paper investigates the link between road attributes and the overtaking gap between cars and cycles. By combining real data on realized overtaking actions recorded with the OBS with OSM information this research paper will exhibit the relationship between distances kept and attributes of the roads. Hence, the researchers will be enabled to draw conclusions for roads designers and city planners. The research will show on the one hand, where crucial overtaking maneuvers are conducted and derived from the knowledge recommendations can be formulated in order to increase safety at these very locations.

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An Automatic Method to Extract Events of Drivers Overtaking Cyclists from Trajectory Data Captured by Drones

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Keywords: cycling safety, road safety, overtaking, vulnerable road users.

1 INTRODUCTION

Cycling as a mode of transportation has been recording an upward trend in both the U.S. and Europe [1]. Unfortunately, the safety of cyclists has been a point of growing concern. Data from the National Highway Traffic Safety Administration (NHTSA) show that the crashes that occur during the events of motorists overtaking cyclists was one of the leading categories involving cyclists in fatal crashes [2]. In support of the efforts to understand the driving behavior of drivers of motorized vehicles while overtaking cyclists, this research project is aimed at developing an algorithm to identify the overtaking events.

Most existing quantitative studies on cycling safety leverage instrumented bicycles or vehicles with sensors for extracting naturalistic driving trajectories. Whereas we use data from a recent research [3] that provides naturalistic driving trajectories of road users collected at select intersections in urban areas in Germany using drones equipped with cameras. Using these videos with a data frequency of 25 Hz, the authors of this study have output inD dataset [4]. The inD dataset contains trajectories of road users that are captured in form of coordinates on a two-dimensional plane obtained from the ariel or bird's eye view of the road. Additionally, the data also captures velocity, acceleration, heading angles, dimensions of driver's vehicle etc.,

Overtaking can be thought of as four phases of approaching, steering away, passing, and returning [5]. Using the inD dataset, we have developed an algorithm to identify events when a driver of motor vehicle overtakes a cyclist. This work fits into our broader goal to contribute to the body of knowledge for improving road safety of cyclists. The work is expected to provide inputs to governmental/ traffic authorities in aspects such as design of intersections and design of bicycle lanes by providing insights into overtaking events.

2 METHODOLOGY

The goal of this paper is to develop an algorithm to automatically extract events of drivers overtaking cyclists from road user trajectory data captured by drones. Figure 1 shows one such overtaking event where the trajectories of driver and cyclist are shown in red and orange curves. The position of driver's vehicle (coded in red rectangle) and that of a cyclist (coded in orange rectangle) are plotted once every 1 second time interval. The triangles within the rectangle are intended to show the heading direction of these road users. The yellow rectangles show the event when the driver is exactly adjacent to the cyclist when in the passing phase. The algorithm provides a method to automatically extract (1) such overtaking events, and (2) safety surrogate measures such as the passing distance from the continuous trajectory data. This would allow researchers to automatically process the data to study the characteristics of drivers-overtaking-cyclists.

First, the existing time-series trajectory data of road users were studied manually to make a note of all cases where cyclists got overtook by drivers, as described in Data Labeling (sec 2.1). Second step was to deploy an algorithm that uses pre-defined thresholds for distance, angles and heading directions to identify overtaking events, (sec 2.2). Then the performance of the algorithm and the misclassifications were studied case-by-case (sec 2.3) followed by measures to tuning the algorithm (sec 2.4) by trying different values of input parameters.

2.1 Data Labeling

The algorithm proposed is aimed at classifying events of overtaking. To test the algorithm for its efficacy, the first step was to create a labeled dataset where events of overtaking were noted. Using the visualization tool [6] provided by the researchers that created the inD dataset, the data, that consists of 33 video recordings of lengths 20 to 22 minutes each, was visually studied to manually identify the overtaking events. 168 events of overtaking were identified. The output of this step was a list of unique identifiers of drivers and cyclists involved in an overtaking-event and the unique identifier of the video recording to which these road users belonged.

2.2 Developing Algorithm

An algorithm to identify the overtaking events was developed using the following variables. The algorithm identifies an event as overtaking if all the conditions of the set values are satisfied simultaneously between any of the driver and cyclist pairs.

(a) Minimum distance between vehicle and cyclist (*d*): This is obtained by computing the minimum of the shortest distance between each of sides of the cyclist and each of the sides of the driver's vehicle. Consequently, this is equal to measuring the perpendicular distance from the corner one of the road users to the side of the other road user, depending on the heading direction and the position of these users as shown in Figure 2. The condition to be satisfied for the variable is $d \leq 3.5$ m.

(b) Passing angle at driver and at cyclist: The passing angle at driver (β) is defined as the angle between the line segment joining the front-center and centroid of the driver and the line segment joining the centroids of the driver's vehicle and cyclist. The passing angle at cyclist (γ) is defined as the angle between the line segment joining the front-center and centroid of the cyclist and the line segment joining the centroids of the driver's vehicle and cyclist. These angles are shown in Figure 2. Condition to be satisfied for these variables are: $85^o \leq \beta \leq 95^o$ and $85^o \leq \gamma \leq 95^o$

(d) Heading difference (δ): Heading difference is the absolute value of difference between heading angles of driver and cyclist as shown in Figure 2. The condition to be satisfied for the variable is $\delta \leq 45^o$

(e) Speed of driver (V_m) and cyclist (V_c) respectively and a threshold speed for driver $v = 5$ km/h such that $V_m \geq v$ and $V_m > V_c$ is another condition to be satisfied. Since an overtaking could be dangerous at high speeds, any events where the driver's speed was lesser than average walking speed of $v = 5$ km/h were ignored

Figure 1: Example of driver-overtaking-cyclist.

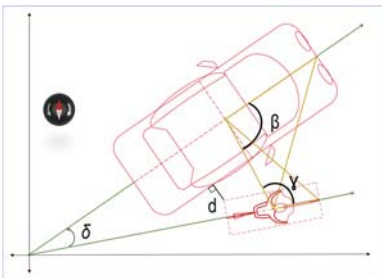

Figure 2: Passing angles and distance, heading difference.

Figure 3: Google Street View of the uniD dataset location

2.3 Performance of Algorithm – Initial Run

Out of the 168 labeled cases of overtaking events, the algorithm identified 142 (true positives), failed to identify 26 events (false negatives) and wrongly classified 6 events (false positives) as overtaking, yielding a sensitivity of 84.52% and precision of 95.95%. This was obtained for $V_m \geq v$ and $V_m > V_c$ where $v = 5$ km/h, $\delta \leq 45^o$, $d \leq 3.5$ m, $85^o \leq \beta \leq 95^o$ and $85^o \leq \gamma \leq 95^o$.

2.4 Tuning Algorithm

Investigating the false negatives, case by case, it was understood that a large portion was contributed by cases where the driver and cyclist were at the initial or final frames in the videos. Such cases needed tuning with regards to input parameters. Thus, a range of inputs were tested with β and γ in range [70º,110º] with increments of 2º, δ in range [25º,65º] with increments of 10º and d in range [2.5 m,5.0 m] with increments of 0.5 m. The classification rates were compared and the passing angles β and γ were further fine-tuned to identify the most favourable outcome.

Our algorithm identifies an event as overtaking when all these conditions are satisfied: $V_m \geq v$ and $V_m > V_c$ where v = 5 km/h, $\delta \leq 25^o$, d ≤ 3.5 m, $76^o \leq \beta \leq 101^o$ and $78^o \leq \gamma \leq 107^o$. Out of the 168 labeled cases of overtaking events, our algorithm identified 154 (true positives), failed to identify 14 events (false negatives) and wrongly classified 24 events (false positives) as overtaking, yielding a sensitivity of 91.67% and precision of 86.52%.

3 OBSERVATIONS

Out of 154 events of overtaking in the inD dataset that were identified by our algorithm, there were 18 cases or 11.69% cases of close-pass events where the passing distance was less than or equal to 1m. The passing distance had a mean = 1.48 m, median = 1.41 m, std = 0.46 m, min = 0.55 m, 25 percentile = 1.19 m, 75 percentile = 1.74 m, max = 3.44 m. There was no correlation between the passing distance and the driver passing speed, probably because of restricted traffic conditions at the intersection with slow moving traffic.

Our algorithm was applied to another dataset called uniD dataset [7] which had the trajectories recorded at a different location, RWTH Aachen University Campus. The Google Street View of a portion of the road is shown in Figure 3. The algorithm labeled 144 cases as overtaking. A manual investigation of these events revealed (a) 94 cases of overtaking events where the cyclist was on the road and was in fact overtook by driver (b) 40 cases where the cyclist was on the sidewalks/bicycle lanes (c) 9 cases where the cyclist was transitioning between the road and sidewalk/bicycle lane, almost the same level as the road (d) 1 no-overtaking.

The scatterplot of passing distance and driver speed and the histograms of the passing distance and driver passing speed of the overtaking cases that were identified by the algorithm are presented in the in Figure 2.

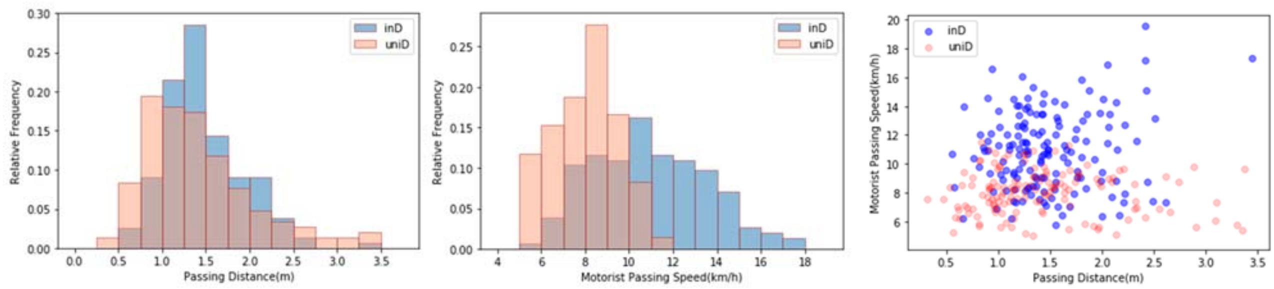

Figure 2: inD and uniD dataset: Distributions of passing distance (left) & driver passing speed and their scatterplot.

4 STUDY LIMITATIONS AND CONCLUSIONS

We developed a method that automatically extracts (1) events of drivers overtaking cyclists and (2) passing distance from trajectory data captured by drones. This method yields a sensitivity between approximately 86% and 92%. Future scope of this work is to enhance the performance of the algorithm by geo-fencing the sidewalks to reduce false positive rates. Extracting other safety surrogate measures for driver-cyclist interactions will be another extension of this work. This work will also be extended to and improved by using drone data collected at more and a wider range of locations.

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Risk Assessment of Cyclist Falls in Snowy and Icy Conditions

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Keywords: winter cycling, cyclist falls, average distance travelled by bicycle, survey effects.

1 BACKGROUND

Cycling as a mean of active mobility comes along with numerous benefits. It is environmentally friendly, inclusive, inexpensive, flexible, space efficient and improves public health thanks to the physical activity related to active mobility [1]. Increased cycling levels can thus help to mitigate the adverse effects caused by motorized private vehicles, particularly in urban areas with their dense structures, mixed land use and multi-modal transport supply. These transport-related problems include congestion, climate change, air pollution, noise, and land consumption. Cycling should therefore be promoted throughout the year. Particularly in wintertime in snowy and icy conditions, high quality cycling facilities are a precondition for encouraging people to cycle and for minimizing risks to fall or to get involved into an accident.

Experience and key data suggest that snow and ice lead to increased numbers of cyclist falls during the winter months. Reliable in-depth data concerning the extent and characteristics of this issue are currently not available in most countries. In Germany, this is due to the high level of under-reporting in official statistics, particularly for incidents involving only one bicyclist. In combination with the lack of knowledge on exposure this causes difficulties to quantify risks for cyclist falls.

2 AIM

This study addresses these gaps. It aims at quantifying the risk of single bicycle accidents in inclement weather conditions. This study focusses on icy and snowy conditions as these are of relevance for the risk to fall. Cyclists are particularly affected by slippery icy and snowy road conditions; these might exist in clear, cloudy, or foggy weather, in situations with high or low humidity and with higher or lower wind speed. Variables from official weather data are purposefully combined in this study to identify time periods with snow or ice on the roads and to allow for the comparison of those with all other time periods (“other weather”).

We address the above-mentioned problems of exposure and underreporting by using multiple data sources for quantifying the risk of falls. This approach allows to compute clear risk ratios for icy/snowy and the other weather conditions and thus contributes to the scarce and fragmented literature that has generated such values so far.

3 METHOD

A total of 5,298 participants reported 5,709 bicycle falls on public roads, paths, and sidewalks from a 5-year period in a retrospective survey. The survey was conducted both online (3,208 respondents) and as a field study in both snowy/icy and other conditions (2,099 respondents). All respondents were also asked about the kind of medical treatment they received and whether the fall was reported to official databases.

We used meteorological data to assign falls and exposure to snowy/icy and other weather conditions and to account for the substantial differences in the number of days for these two situations. We defined days as "snow or ice" when either previously fallen snow has not yet thawed, new snow has fallen and/or liquid precipitation falls during the day with minimum temperatures close to freezing point.

For quantifying risk exposure, we analyzed data from the trip-based household travel survey (HTS) "Mobility in Cities – SrV" [2]. For this purpose, the daily distances travelled by bicycle by all 22,772 respondents in either snowy/icy or other conditions on their respective reporting day were calculated.

We then calculated the risk in the form of cyclist falls per distance by dividing (1) the mean number of falls per person and study period by (2) the mean distance travelled by a person on a day with specific weather conditions and (3) the number of days with such weather conditions per period.

$$Risk = \frac{Falls}{Distance} = \frac{\frac{Falls}{Person * Period}}{\frac{Distance}{Person * Day} * \frac{Days}{Period}} \quad (1)$$

4 RESULTS

4.1 Distances travelled by bicycle

HTS respondents reported an average distance travelled by bicycle of about 1.5 km per person per day. When there was snow or ice on the reporting day, this average distance was only about 0.8 km per person per day (see figure 1). This is a statistically significant decrease of about 50 %, which is in line with findings from literature, e.g., 47 % reduction in number of bicycle trips by Bergström and Magnusson [3].

Overall, women reported cycling an average of 40 % less distance than men. Among the age groups, the 18–44-year-old reported the greatest average daily cycling distance of about 2.3 km per person. In contrast, those over 65 reported significantly shorter distances of 0.7 km per person per day on average.

Due to the smaller sample sizes of reporting days with snow or ice (around 15 % of respondents), no significant difference between genders or age groups can be observed in the decrease in average cycling distance per person per day with snow or ice. However, respondents aged 65 or older reported the highest average decrease at 70 %.

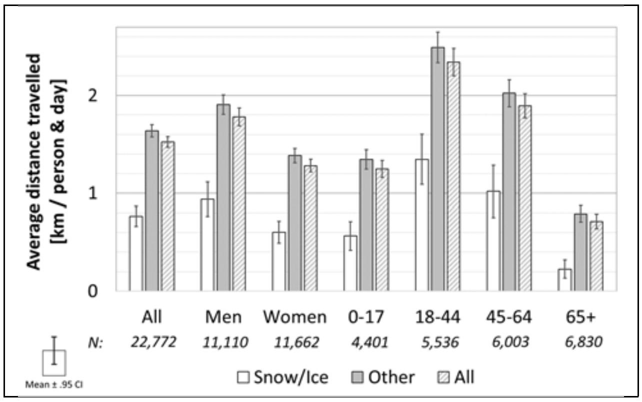

Figure 1: Average daily cycling distances covered by HTS respondents in various weather conditions, by gender and age (N=HTS respondents)

4.2 Risk of falling with a bicycle

On average, all respondents in our field surveys reported 57 crashes per 1,000 person-years. A similar rate of 55 per 1,000 person-years was found by Olesen et al. [4] for single bicycle crashes, but among active cyclists in Denmark. In contrast, participants in our supplementary online survey, which also took place during a period of snow and ice, reported an average of 319 falls per 1,000 person-years. We suspect a non-response bias as the reason for this difference, since due to the topic of the survey (winter service on footpaths and cycle paths) more active cyclists with many experienced bicycle falls may have participated.

Taking exposure into account (traffic volume and temporal proportion of weather conditions), 0.9 falls per 10,000 km travelled were reported during the field surveys conducted in snow/ice (see figure 2). This was less than during the field surveys conducted in other weather conditions (1.2 falls per 10,000 km travelled). During the online survey, an average of 5.7 falls per 10,000 km travelled were reported.

Results from all three surveys show a significantly higher average risk of falling by bicycle in snow/ice than in other weather conditions. However, the main differences in snow/ice risk ratios are not between online and field surveys, as is the case with the total falls per distance travelled, but between the weather conditions at the time of the field surveys: The average risk ratio based on the online survey is 38 and based on the field survey during snow/ice 36, while it is only 20 based on the field survey during other weather. There is a tendency of lower risk ratios among respondents aged 45 and older, but these differences are not statistically significant.

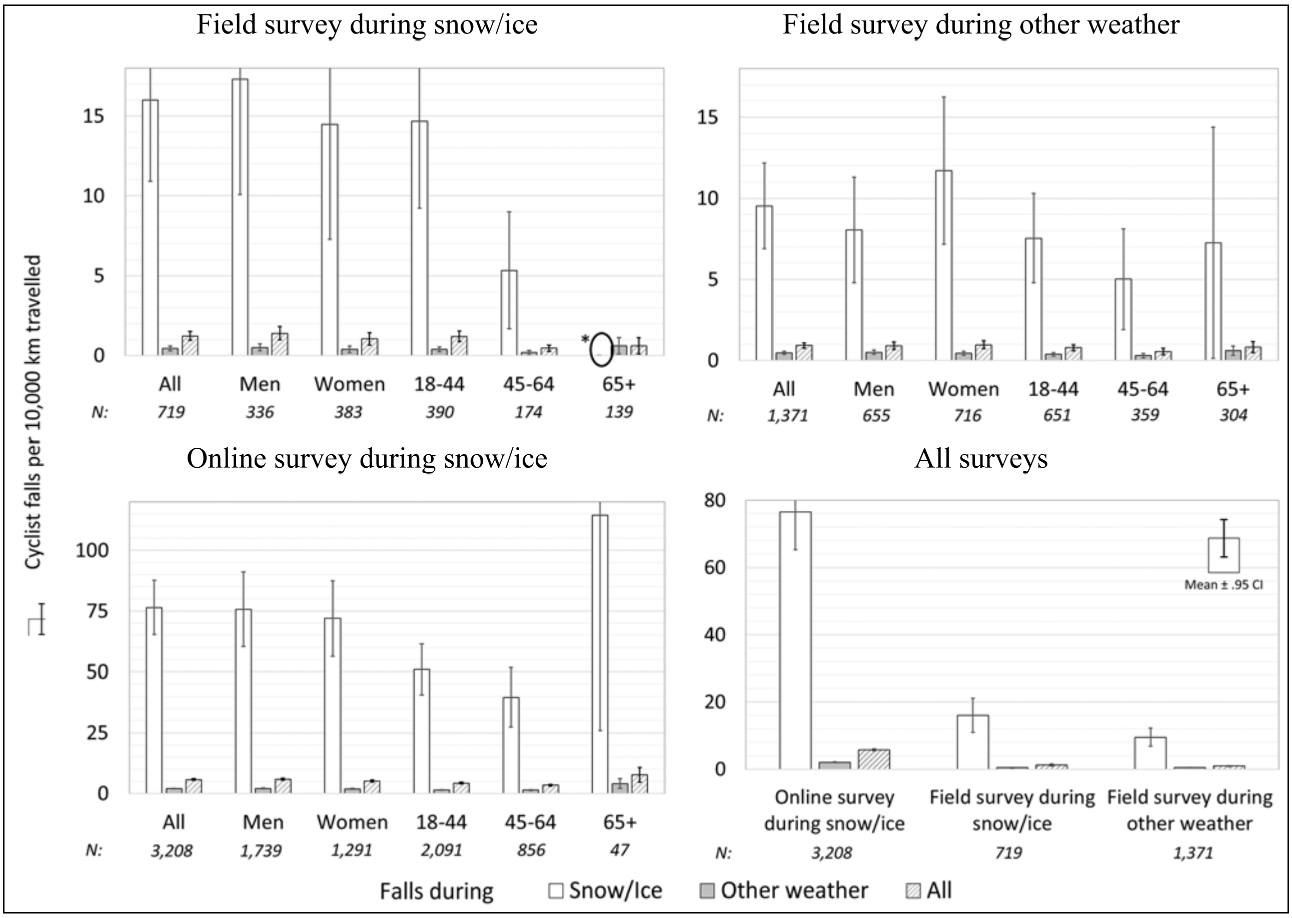

Figure 2: Cyclist falls per 10,000 km travelled in different weather conditions by gender and age reported in field survey during snow/ice (top left), field survey during other weather (top right), online survey during snow/ice (bottom left), and compared for the three surveys (bottom right, total only).
*(N=Respondents, *No data about falls on snow/ice)*

5 CONCLUSIONS

With this study, we provide data on cyclist falls and exposure to address the mentioned lack of knowledge. The risk ratios calculated from different data sources underline the high importance of improving winter maintenance on cycling facilities. Also, the findings provide helpful insight into the extent of survey effects, which can be taken into consideration when designing future studies.

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Importance of safety and road surface for route choice when riding shared e-scooters vs. bicycles

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Keywords: micromobility, route choice, cycling safety.

1 INTRODUCTION

The rise of micromobility, most notably electric standing scooters (e-scooters), has resulted in new challenges for traffic planning and road safety. One such issue is the fact that in most European countries, e-scooter users are obliged to ride their vehicle on cycling infrastructure and thereby share this infrastructure with bicyclists. This increases the use of and, subsequently, demand for bicycle lanes, which is an obvious challenge for transport planning [1]. However, for adequate planning and construction of cycling infrastructure, information on route choice behavior of bicyclists and e-scooter users and its influencing factors is necessary. While research on bicyclists' route choice is well advanced, research on e-scooter riders is still in its infancy. For bicyclists, the presence of bicycle facilities, traffic volume, and travel time are among others particularly important for route choice [2–4]. However, the question arises whether this also applies to e-scooter riders as vehicle dynamics are different and riders are, at least for now, less skilled due to lack of training and exposition. In order to fill this research gap, we aimed to analyze the determinants for route choice of e-scooter users in comparison to bicyclists in a field study.

2 METHODS

Within the field study, participants had to ride with either a shared e-scooter or a shared bicycle to reach four destinations. The riders chose the appropriate routes themselves and were subsequently asked to report about the reasons and circumstances of their decisions. The first part of the study was conducted with shared e-scooters in August and September 2021 [5] and the second part with shared bicycles in April 2022. When selecting the four destinations, the aim was that each of the origin-destination (OD) pairs would result in a length of the routes to be driven of approx. 1.5 - 2 kilometers which represents the average trip length of e-scooter rides in Germany [6]. The four OD pairs differ regarding relevant route choice criteria, especially in terms of directness (number of turning maneuvers), presence of a (separated) bike lane, available scenic routes, roadway condition, and traffic volume.

Appointments for study participation were given for working days either at 2 p.m., 4 p.m. or 6 p.m. At the beginning of the study, subjects were instructed with the procedure and their riding task. After a brief introduction to the vehicle's features and, in the case of the e-scooter, a short practice parkour, the subjects started the test ride either with a shared e-scooter or a shared bicycle in the city of Dresden. The ride was instructed as a leisure trip without cost or time pressure and participants were asked to ride as they normally would. Participants then had to ride to four destinations in succession. After completing the ride and parking the vehicle, they answered questions about the ride and completed a questionnaire on demographic characteristics and other variables.

A total of 52 subjects participated, split evenly between the two studies. Participants were acquired via social media through the university's' Twitter and Instagram channels. The subjects of both the e-scooter study (18 male, 7 female, 1 diverse) and the bicycle study (20 male, 6 female) were on average 23 years old. The majority of them held a driver's license (92 % and 89%) and reported an above average local knowledge of the city (between 6 and 7 on a scale from 1-very bad to 10-very good). No statistical differences existed between both samples regarding sociodemographic features except for the frequency of use of e-scooters which was significantly increased for participants riding with the e-scooter.

The data obtained consisted of GPS position for the four ODs and questionnaire data, specifically (1) ratings of the importance of route choice factors, (2) the number of alternative routes that the participants considered, other the one ridden, and (3) a subjective rating of how difficult or easy it was to decide. Due to ongoing data analysis, riding related measures cannot be presented in this abstract. However, at the ICSC 2022 we aim to present mean distances, mean velocity and percentage use of secondary roads.

3 RESULTS

The importance of thirteen possible route choice factors was rated on a 10-point Likert scale. Figure 1 (left) shows the results of the median ratings for both studies and all factors. E-scooter riders considered safety and road surface much more important than bicyclists [safety: U = 162.50, z = -3.22, p = .001, r = -.45 / road surface: U = 191.00, z = -2.70, p = .007, r = -.37]. In fact, safety and road surface were the overall most important route choice factors for e-scooter riders. Further differences between both user groups existed in terms of importance of rule compliance (how easy / difficult it would be to follow traffic rules along a certain route) [U = 220.50, z = -2.16, p = .031, r = -.30] and travel distance [U = 451.50, z = 2.09, p = .001, r = .29]. E-scooter riders rated rule compliance more important for route choice than bicyclists, while bicyclists rated travel distance more important than e-scooter riders did.

Participants reported between zero and four alternative routes that they considered for each trip. Results for all four route choices are shown in Figure 1 (top right). The average number of reported alternative routes ranged mostly between 0.5 and 1. Only for one of the OD pairs (No. 2), e-scooter riders reported a higher number of alternative routes [U = 220.50, z = -2.16, p = .031, r = -.42], however, medians for both groups were equal (1). No differences in reported number of routes were found between e-scooter riders and bicyclists for any of the other OD pairs.

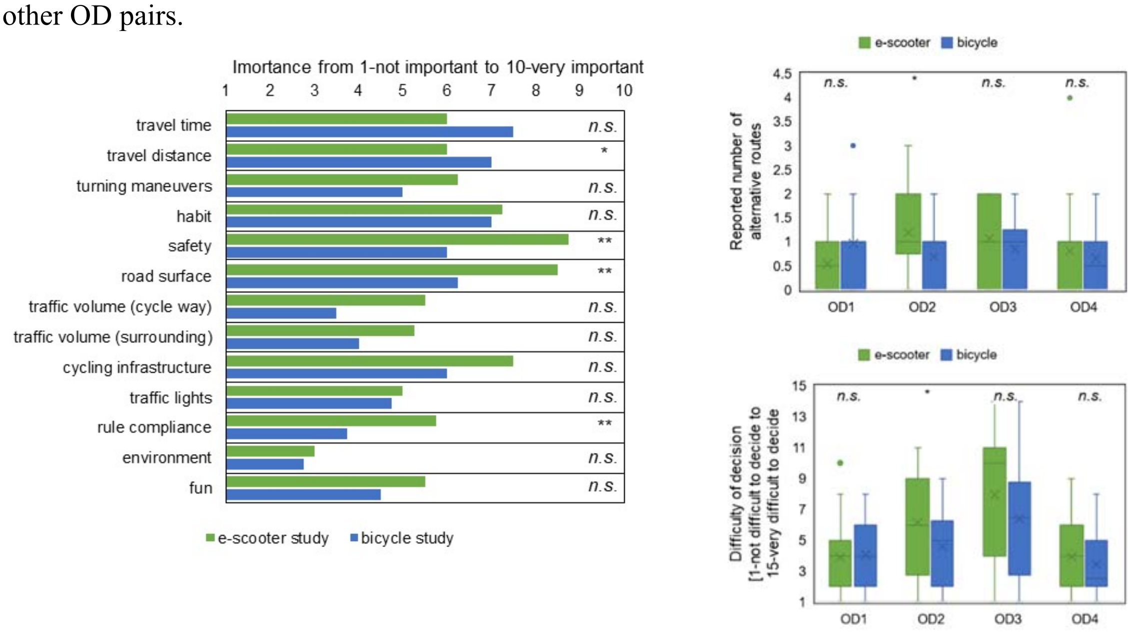

*Figure 1: Medians of importance of route choice factors for both studies (left). Box plot for reported number of alternative routes (top right). Box plot for subjective estimation on difficulty of decision (bottom right). Significance *- p >.05, ** - p > .01, n.s. – not significant. OD – origin-destination pair.*

In order to test whether decision-making might be more difficult when riding an e-scooter, we surveyed how easy or difficult it was for the subjects to make a route choice decision for each OD pair. Results are shown in Figure 1 (bottom right). One can clearly see, that decisions for some OD pairs were easier to make than for others. Differences in ratings of e-scooter riders and bicyclists were found for one OD pair with a rather small effect showing that e-scooter riders found the decision slightly more difficult than bicyclists [$U = 231.50$, $z = -1.97$, $p = .049$, $r = .27$]. For all other OD pairs, no difference between e-scooter riders and bicyclists were found.

4 DISCUSSION AND CONCLUSION

The results of both studies showed that e-scooter riders and bicyclists clearly differ regarding the importance of factors determining route choice. Although e-scooter riders did not really consider more or fewer route options for their route choice, the factors they considered important in making the decision were different from those relevant to bicyclists. In contrast to bicyclists, safety and road surface as well as the question of how easy or difficult it would be to follow traffic rules along a certain route were much more important to e-scooter riders for route choice. This suggests that high-quality and safe cycling infrastructure is even more important to e-scooter riders than for cyclists which may be due to the fact that the handling of the small wheels is more difficult on uneven surfaces. Accordingly, the road surface condition of bike lanes should be improved and regularly maintained. Nevertheless, it is not known at this time which other aspects are relevant for e-scooter riders' perception of safety and the following of traffic rules. It can be assumed that the inexperience of e-scooter riding is one reason for increased importance of safety and complying with traffic rules in route choice when choosing routes. These safety concerns could, in turn, tempt e-scooter riders to use footpaths when cycling infrastructure is lacking or poor. Further research should check the influence of riding experience and the interrelationship with road infrastructure use for route choice. Regarding the management of transport, future transport planning needs to consider differences between bicyclists and e-scooter riders. In order to construct new bike lanes and upgrade existing ones, the results of this study provide a helpful basis for considering the requirements of both user groups.

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Different but also alike?
Ingroup-outgroup phenomena among cyclists and e-scooter riders.

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Keywords: micromobility, e-scooter, social identity, stereotypes, rule violation.

1 INTRODUCTION

Against the background of an increasing number of cyclists sharing the infrastructure with an also rising number of e-scooter riders in Germany, the question of considerate coexistence among both modes of transportation, especially on shared infrastructure (on- or off-road) arises.

In various contexts (e.g. work, education), studies have shown that social identity has an impact on how members of an ingroup (“us”) and outgroup (“them”) are perceived [1]. These studies are based on social identity theory [2], which postulates members of the ingroup are more likely to be favored and members of the outgroup are more likely discriminated and stereotyped.

This ingroup favorism or outgroup discrimination can refer to attitudes, cognition, and behavior. Initial research in the traffic context by [3], on which the present study builds, suggests that social identity also plays a role in traffic. Apart from that, research on social identity in traffic is scarce.

The aim of the study is to determine whether the role as cyclist or e-scooter rider in traffic can serve as social identity, and subsequently whether ingroup-outgroup phenomena, such as ingroup favorism and effects of outgroup discrimination can be observed.

2 METHODS

Currently, cyclists and e-scooter riders are recruited Germany-wide through an existing list of subjects, online forums about e-scooters and social media. To address the research aims, an online experimental survey was conducted that takes roughly 15 minutes to complete. Dependent on their stated usage frequency of e-scooters and bicycles participants are assigned to the respective group (between-subjects factor) and randomly assigned to watch either video clips showing an e-scooter rider or cyclist. Before the videos start participants are asked to indicate the degree of identification with the assigned group (social identification as e-scooter rider/ cyclist).

The six video clips were recorded from the perspective of a cyclist/ an e-scooter rider (the survey participant) following another road user (e-scooter rider/ cyclist). The participants are instructed to envision themselves as being on the road cycling/ e-scooter riding and observing the scene from the video in front of them. The road user shown in the video clips commits one rule violation in each of the six clips, pictured in Table 1.

Table 1: Clip snippets of the six different rule violations per condition rated by the participants.

	Cyclist	E-Scooter rider
Taking the right of way		
Overtaking too closely		
Riding two on one vehicle		
Riding against the direction of travel		
Close cutting in		
Side by side riding		

Each time a video ends, participants are asked to rate on a six-point Likert-scale their agreement with three given internal and external attributions regarding the observed rule violations by the shown road user. In addition, participants are asked to indicate their willingness to raise traffic fines for the observed rule violation and the respective amount of this fine.

The survey closes with the collection of demographic information.

3 RESULTS

At the time of submission, data collection is still ongoing.

4 OUTLOOK

Stereotypes and their negative companions, e.g. aggression, become effective especially in situations with high cognitive load and under time pressure [4], situations that occur frequently in road traffic. Against this background, the results of this study can provide initial indications of whether, in the coming years, we can expect considerate coexistence among e-scooter riders and cyclists or, in the worst case, aggressive riding behavior on shared cycling facilities.

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