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Traffic conflicts and their contextual factors when riding conventional vs. electric bicycles

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ABSTRACT

The prevalence of electric bicycles (e-bikes) has increased considerably in the past few years. Because of their potential to reach higher speeds than conventional bicycles, concerns have been raised about a possible increase in traffic conflicts and crashes. The goal of this study was to examine if there are differences between conventional cyclists and e-bike riders with regard to the probability to be involved in a traffic conflict. In addition, the circumstances under which conflicts occur were investigated to identify potential differences in risk dependent on contextual factors. Utilising the naturalistic cycling approach, the personal bicycles of 80 participants (31 conventional cyclists and 49 e-bike riders) were equipped with a data acquisition system that included two cameras and a speed sensor. Four weeks of "normal" cycling were recorded for each participant. The analysis showed no difference between bicycles and e-bikes with regard to their overall involvement in traffic conflicts, as well as for the role of most contextual factors. One notable exception were intersections, where the risk of being involved in a conflict was twice as high for e-bikes as for conventional bicycles. The riders' speed patterns immediately preceding a conflict were similar to the patterns in mean speed, with higher speed for riders of e-bikes compared to conventional bicycles. While the general safety concerns regarding e-bikes could not be confirmed, the finding that e-bike riders are somewhat more at risk around intersections shows that under specific circumstances, other road users might still need time to adapt to this relatively new type of vehicle.

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1 INTRODUCTION

The number of electric bicycles (pedelecs as well as S-pedelecs[2]) in the market has grown considerably in the past decade. In Europe, sales figures have increased from about 100.000 units in 2006 to nearly 1 million e-bikes in 2013 (COLIBI & COLIPED, 2014). The main reasons for this popularity include the reduction in cycling effort, reduced physical strain and the ability to ride for longer trips (Jellinek, Hildebrandt, Pfaffenbichler, & Lemmerer, 2013). However, there are growing safety concerns. The e-bikes' potential to reach higher speeds could lead to problems for the cyclist alone (who might not be able to control the bike at high speed), and, even more critically, to conflicts in the interaction with other road users (who might underestimate the e-bike's speed; bfu-Beratungsstelle für Unfallverhütung, 2014; Skorna et al., 2010). While there is no agreement on the absolute magnitude of the difference between the speed with which conventional bicycles and e-bikes are moved in traffic (often dependent on which specific type of e-bike is observed), it is clear that there are indeed differences in operating speed (Alrutz, 2013; Jellinek et al., 2013; Langford, Chen, & Cherry, 2015; Lin, He, Tan, & He, 2007). In addition, a recent test track study found that motorists accepted shorter time gaps for crossing in front of an approaching e-bike compared to a conventional bicycle (at the same speed), just as they accepted shorter time gaps when the approaching bicycle was faster (Petzoldt, Schleinitz, Krems, & Gehlert, in press). Interview data indicate that this effect can be found also in the field, as e-bike users repeatedly reported that they were under the impression that other road users were not expecting them to approach as quickly as they did, and as a consequence, cut them off or violated their right of way (Bohle, 2015; Popovich et

[2] In Germany, we distinguish between so called pedelecs, which support pedalling up to 25 km/h (250W), are legally treated as conventional bicycles and constitute 95% of e-bikes sold (Zweirad-Industrie-Verband, 2015), and the faster S-pedelecs, which support up to 45 km/h (500W), and are legally categorised as powered two wheelers, i.e. the rider needs to be in possession of a moped driving licence, and is required to wear a helmet (Lawinger & Bastian, 2013). Similar categorisations (often with consequences for licensing, insurance etc.) exist in most European countries (Jellinek et al., 2013).

al., 2014). Taken together, it appears that e-bike riders might indeed be at a higher risk of being involved in traffic conflicts and crashes than users of conventional bicycles.

Unfortunately, actual crash data are hardly available. Until today, only Switzerland has gathered crash data on e-bikes for a considerable period of time in Europe (bfu-Beratungsstelle für Unfallverhütung, 2014; Weber, Scaramuzza, & Schmitt, 2014). While a clear increase in crashes with injuries involving e-bikes is reported, the authors acknowledge that the most likely explanation for this is the rapid increment of e-bike ridership. Therefore, researchers have to rely on other means to assess crash risk. A survey of cyclists seeking treatment at hospital emergency departments found that e-bike users were more likely to be involved in a crash that required treatment (Schepers, Fishman, den Hertog, Wolt, & Schwab, 2014). It might be argued that this increased likelihood to be involved in a crash requiring hospitalization is not necessarily the result of a higher crash risk, but rather a higher crash severity when a crash does occur (i.e. a higher percentage of crashed e-bike riders end up in hospital) given e-bike riders' increased speed (Scaramuzza, Uhr, & Niemann, 2015; Schepers, Fishman, et al., 2014). Such a "reporting bias" must be expected also for actual crash statistics, once they become available (Janstrup, Hels, Kaplan, Sommer, & Lauritsen, 2014).

Field observations of road user behaviour appear to be a promising alternative to the investigation of actual crashes. So called *Naturalistic Driving Studies* (NDS), in which cars are instrumented with cameras and sensors to record "driver behaviour in a way that does not interfere with the various influences that govern those behaviours" (Boyle et al., 2012, p. 45), have been conducted for nearly two decades. As this approach does not usually yield a sufficient number of actual crashes to analyse, researchers look into safety critical events, which are used as a proxy for actual crashes (Guo, Klauer, McGill, & Dingus, 2010; Heinrich, Petersen, & Roos, 1980). These events include traffic conflicts as defined by Amundsen and Hydén (1977) as well as single vehicle incidents (e.g. run-off-road events). Due to technical limitations, only in recent years has this method become attractive also for the research of cyclist behaviour (Dozza & Werneke, 2014; Gustafsson & Archer, 2013; Johnson, Charlton, Oxley, & Newstead, 2010; Knowles, Aigner-Breuss, Strohmayer, & Orlet, 2012). Following this naturalistic approach, Dozza, Piccinini, & Werneke, (in press) instrumented e-bikes with sensors and cameras to observe riders' natural cycling behaviour. The circumstances under which the risk of a conflict increases was assessed, and compared to results from a previous study that used conventional bicycles (Dozza & Werneke, 2014). The findings indicated that the situations under which the risk of a conflict increases differ between the bicycle types. However, the authors did not directly answer the question of whether certain situations are riskier for one bicycle type compared to the other.

The goal of the study presented in this paper was to investigate traffic conflicts for both conventional cyclists and e-bike riders. To accomplish that, we conducted a naturalistic cycling study that included users of both types of bicycles. The central question was whether we would find significant differences in the probability to be involved in a traffic conflict depending on bicycle type. In addition, we assessed the circumstances under which such conflicts occurred, in order to identify potential differences in risk dependent on contextual factors.

2 METHOD

2.1 Participants

Participants were recruited through different media, including ads in newspapers and flyers in cycling shops. Out of a larger pool of applicants, we selected those candidates for participation that used their bicycle or e-bike at least three days per week, cycled only in Chemnitz and the surrounding areas, and were the only user of the bicycle / e-bike. In addition, e-bike riders were required to have at least three months of experience riding an e-bike. In the end, a total of 80 participants (33 female, 47 male) took part in the study. Thirty-one of our participants (12 female, 19 male) owned a conventional bicycle (without motor assistance), 49 (21 female, 28 male) owned a pedelec[3]. As the e-bike user population is currently skewed towards older riders, we first recruited the e-bike riders to then match our sample of conventional cyclists in terms of age. We created three age groups: ≤ 40 years; 41 - 64 years; and ≥ 65 years. Table 1 shows the distribution of participants across age groups and bicycle types. Participants received a monetary compensation of 100€ for their collaboration.

Table 1: Overview of demographic data.

	Total sample (*N* = 80)					
	Bicycle			E-bike		
Age groups	*N*	*M age*	*SD age*	*N*	*M age*	*SD age*
≤ 40 years	10	30.7	6.2	16	33.1	6.5
41 - 64 years	10	52.4	8.0	14	54.1	7.2
≥ 65 years	11	69.5	3.2	19	70.4	3.2
Total	**31**	**51.5**	**17.2**	**49**	**53.5**	**16.8**

***** N = Number of participants, M = mean, SD = standard deviation

2.2 Data acquisition system (DAS)

Participants' own bicycles and e-bikes were fitted with a small data acquisition system (Figure 1). This system consisted of two cameras (Type ACME FlyCamOne eco V2), a speed sensor (2 Hz) and a battery. One camera recorded the forward scenery and the other the riders' upper body (30 Hz with a resolution of 720x480 pixels, 80° field of view – see Figure 2 for an example of the forward view). Both cameras were placed inside a small box, which was mounted on the handlebar of the bike (Figure 1, right). Data were recorded on two SD-memory cards, one for video (32 GB) and the other for speed data (4 GB). A flip switch on the DAS box allowed participants to start and stop the data acquisition.

[3] An additional group of 10 riders of S-pedelecs participated as well. However, due to its small size (and the arising consequences for data analysis), this group was not included in the analysis reported in this paper.

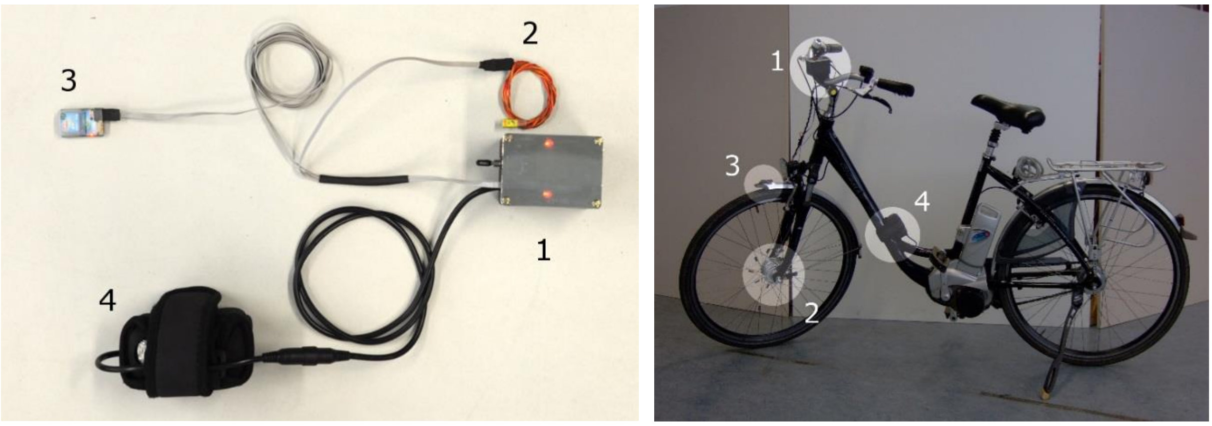

Figure 1: Left: components of the data acquisition system. (1) box with cameras and LEDs (top view); (2) speed sensor; (3) GPS sensor; (4) battery package. Right: components attached to a participant's e-bike. (1) box with cameras and LEDs; (2) speed sensor (including magnets); (3) GPS sensor; (4) battery package.

Figure 2: Example of the forward view of the camera.

2.3 Procedure

The study was conducted in and around Chemnitz (Germany), with overall data collection from July to November 2012. This resulted in a considerable range of weather conditions during data acquisition, varying from hot, sunny and dry in summer, to cold, wet and windy in autumn. For each participant, we collected four continuous weeks of cycling data during this period. Participants were instructed to use their bicycle/e-bike during the study period as they normally would and to record

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every single trip made. Maintenance procedures (DAS repairs and exchange of storage media) were carried out by trained technicians whenever needed.

During DAS installation, participants completed a pre-study questionnaire. This questionnaire included a variety of questions regarding their cycling behaviour, among which there were some items on the purpose of their usual cycling trips. Participants were also asked to complete a short test ride in the yard of the institute, during which their stability when mounting, riding straight and dismounting was judged by a test supervisor in three broad categories (no issues, minor issues, major issues – data available for 70 participants). None of the participants was rated as having major issues. In the two younger groups, all but one rider were rated as having no issues at all. In the older group, still a majority of riders was rated as having no issues (77.8% conventional cyclists, 52.9% e-bike riders).

After the four weeks of data acquisition, the DAS was dismounted. During the procedure, participants filled in a post-study questionnaire, which contained questions about their involvement in traffic conflicts during the study period. If any involvement in a conflict had occurred, they were supposed to provide a description of the circumstances of each conflict. Participants were also asked if they had always activated the DAS, and if not, why. Participants' replies indicate that some trips might have been lost, but the reasons usually provided for not activating the system ("forgotten", "battery dead") imply there would be no systematic pattern in these lost trips.

2.4 Data analysis

First, speed sensor data were analysed to obtain general information on trip length, time of trip and cycling speed. For the investigation of differences between bicycle types, age groups and sexes, ANOVAs were calculated for the relevant variables. However, as the focus of this paper is on traffic conflicts, this data are only reported to provide a general overview of the dataset (for a detailed analysis of this data see Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, in press).

As a second step, the video material for every recorded trip was inspected. In total, 4,028 video clips with about 1,030 hours of cycling were screened. We followed Reynolds and colleagues' definition of traffic conflicts in cycling which characterises them as the "interaction between a bicyclist and another road user such that at least one of the parties has to change speed or direction to avoid a collision" (Reynolds, Harris, Teschke, Cripton, & Winters, 2009, p. 4). This definition is based on the broader definition of traffic conflicts in general as "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged" (Amundsen & Hydén, 1977). This definition has often been used in studies that analysed video material from site based traffic observations, where measures such as minimal distance, time to collision or post encroachment time have been used as operationalisations of conflicts and their severity (Kruysse, 1991; Lord, 1996; Sayed & Zein, 1999; van der Horst, de Goede, de Hair-Buijssen, & Methorst, 2014). Given the fact that our data are not from a static environment, but rather dynamic material from which we cannot derive all the necessary information to compute such measures, we instead had to rely on video annotators' judgements of the observed scenes. Following the definition, a certain situation qualified as a conflict if there either was an actual collision, or if one or more parties involved had to brake or change direction to avoid such a collision. This required clearly visible (re-)actions by our cyclist or the conflict partner, e.g. hard braking or sudden swerving manoeuvres. It had to be clear that the (re-)action was not simply part of a regular manoeuvre, such as a cyclist moving in his lane to accommodate oncoming traffic or to overtake, but rather some form of emergency (re-)action. All annotators were experienced cyclists, which helped them judge whether a certain re(-action) can indeed be considered conflict avoidance in the narrower sense of the definition. This judgment was simplified by the analysis of the cyclists' and conflict partners' additional responses, such as facial expression, gesturing and posture. As Bärgman (2015) noted for the analysis of naturalistic driving data: "When a facial expression or change in body posture reveals surprise ("oops") or even dread, the driver is likely to be experiencing an SCE [safety critical event]" (p. 27). The combination of this form of response and a fast avoidance reaction can be considered a credible indicator of traffic conflicts (Dozza & González, 2013). In addition, participants' reports on traffic conflicts during the data collection period (as provided in the post-study questionnaire) were used to validate our potential conflicts.

To ensure the quality of the annotators' judgements, we based our overall annotation procedure on the process proposed by (Klauer, Perez, & McClafferty, 2011). Our procedure included detailed instructions with regard to the definition of a cycling conflict and a training (including also the classification system used for later annotation) on a variety of example videos. Each potential conflict identified in the inspection was reviewed and discussed within the group of annotators and the senior researcher before a decision was taken to include or not include it in the final set of events. In addition, a verbal description of the event was added to allow for a better characterisation of the situation. This description was standardised in a way that allowed us to categorise the events.

We also considered including situations in which a participant (nearly) crashed without interacting with another road user (single vehicle events). However, such events are very difficult to spot and evaluate (unless the rider obviously crashes), so we decided to focus on the conflicts as defined previously. Participants' mean number of conflicts, dependent on bicycle type, age group and sex, were compared using non-parametric tests for non-normally distributed data (Mann-Whitney and Kruskall-Wallis-test). As exposure obviously might influence conflict numbers, the same tests were conducted again after data were corrected for distance travelled by calculating a safety incident rate (SIR, the number of conflicts per 100 km travelled (OECD/International Transport Forum, 2013).

The core of our analysis was the in-depth assessment of each traffic conflict to identify contextual factors that might increase risk. For this purpose, the circumstances under which the conflicts occurred were annotated along a set of different factors (Table 2), which were selected based on previous studies that reported a potential increase of risk for the respective factor. The factors included not only aspects of the road environment (e.g. infrastructure type or road surface), but also behavioural aspects (participant and other road users) with potential implications for the development of a conflict. To be able to calculate the risk associated with the different contextual factors, we extracted baseline events from the dataset (twice the number of identified conflicts). The number of sampled events per participant was matched to the number of conflicts we found for this participant. Other than that, the extraction of baseline events was completely random (with the restriction that the bicycle / e-bike must have been in motion). The baseline events were characterised along the same variables as the traffic conflicts.

Table 2: Overview of the annotated (categories of) potentially influencing factors. Indented factors are a subset of the respective higher level factor.

Annotated factors	Description/Examples	References
Other road user		(Dozza & Werneke, 2014; Martínez-Ruiz et al., 2013; Rivara, Thompson, & Thompson, 1997)
Vehicle ≤ 3,5t	Car, compact van, pick-up truck	
Car		
Other cyclist/e-bike rider		
Pedestrian		
Pedestrian and dog		
Used infrastructure		(De Rome et al., 2014; Lusk et al., 2011; Reynolds et al., 2009)
Carriageway	Part of a road used by cars etc.	
Bicycle infrastructure	Bicycle lane, bike path	
Pavement	Footpath along the sides of a road	
Unpaved path	Forest path, field path	
Intersection type		(Dozza & Werneke, 2014; Harris et al., 2013; Johnson et al., 2010; Reynolds et al., 2009; Stone & Broughton, 2003)
Intersection (all)		
Intersection with traffic light		
Intersection left yields to right/priority sign		
Road gradient		(Cripton et al., 2015; Harris et al., 2013)
Uphill		
Downhill		
Flat		
Road surface		(Gustafsson & Archer, 2013; Nyberg, Björnstig, & Bygren, 1996)
Paving stones		
Poor conditions of road surface	Potholes, roots, broken road edges	
Obstacle	Bollards, stones, railings, signs, traffic lights, work zones	
Other factors		(Bacchieri, Barros, Dos Santos, & Gigante, 2010; Martínez-Ruiz et al., 2013; Schramm, Rakotonirainy, & Haworth, 2010)
Infringement of traffic regulations	Using the wrong type of infrastructure e.g. pavement instead of carriageway, failing to yield, overtaking on the wrong side, riding through red lights, riding in the opposite direction of traffic	
Being overtaken	Participant overtaken by another cyclists/e-bike rider or a motorised vehicle travelling in the same direction	

With the conflicts and baseline events fully annotated, odds ratios (OR), with 95% confidence intervals (CI), were calculated using cross tabulations. For this calculation, only participants who experienced at least one traffic conflict were included in the dataset, which reduced the participant sample size for this analysis to n = 61. Demographic data for these participants (Table 3) show no

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obvious differences to the full sample (Table 1) with regard to age and age distribution. The distribution of male (40) and female (21) participants also did not differ substantially from the full dataset. First, ORs for the different contextual factors were calculated separately for bicycles and e-bikes to assess the potential impact that the presence each of these factors might have on conflict occurrence (e.g. "when riding an e-bike, what is the risk of being involved in a traffic conflict when cycling on the pavement, compared to cycling elsewhere?") (Dozza & Werneke, 2014). Then, conflict rates for the two bicycle types were compared directly for each of the factors (e.g., "when cycling on the pavement, what is the risk of being involved in a traffic conflict when riding an e-bike compared to riding a conventional bicycle?").

Table 3: Overview of demographic data of participants who experienced at least one traffic conflict.

Sample for odds ratio calculation (n = 61)					
Bicycle			E-bike		
N	*M age*	*SD age*	*N*	*M age*	*SD age*
8	31.6	6.5	12	32.0	6.9
8	54.6	7.4	10	53.8	7.0
6	69.8	3.4	17	70.7	3.2
22	**50.4**	**17.5**	**39**	**54.4**	**16.9**

In a final step, we went back to the collected speed sensor data. Aim of that was to characterise the traffic conflicts with regard to the speed immediately preceding the conflict. As it was hypothesised that e-bikes' potential to reach higher speed levels might put them at a higher risk of being involved in traffic conflicts, it was important to not only analyse overall mean speed (as described previously) for the different bicycle types, but also to clarify at which speed the rider was cycling when the actual conflict occurred. For that, mean speed over a period of 10s preceding the onset of the conflict was calculated. Due to the reduced sample size (and considerable variations in cell size) for this analysis, results are only reported on a descriptive level.

3 RESULTS

3.1 General travel behaviour

Due to technical issues (missing speed sensor data for four participants), we had 76 usable datasets with a total mileage of 14,445 kilometres for the analysis of cycling distance and speed. On average, each participant cycled about 189.4 km during the four weeks of data collection. Table 4 shows the mean distance cycled for the two bicycle types, both for the three age groups and two sexes. While on a descriptive level, there appear to be some differences, especially between male and female riders, the ANOVA revealed no significant main effects for bicycle type (F (1, 64) = 0.01, p = .971, η^2_p = 0.00), age group (F (2, 64) = 1.42, p = .250, η^2_p = 0.04) or sex (F (1, 64) = 2.40, p = .126, η^2_p = 0.04). There was also no interaction effect between any of these factors.

Table 4: Mean distance travelled per bicycle type, age group and sex (*n* = 76).

	Bicycle (*n* = 28)				E-bike (*n* = 48)			
	M	*SD*	*Min*	*Max*	*M*	*SD*	*Min*	*Max*
≤ 40 years	149.1	69.7	64.5	291.1	166.7	114.0	53.1	471.8
41 - 64 years	210.9	113.3	42.8	411.0	193.4	110.7	65.9	446.3
≥ 65 years	198.3	131.4	30.2	425.8	206.1	61.5	111.9	324.2
Male	215.2	120.2	30.2	425.8	204.3	98.0	65.9	471.8
Female	146.7	80.5	49.6	340.2	171.7	89.5	53.1	347.9
Total	**188.3**	**110.1**	**30.2**	**425.8**	**190.1**	**94.8**	**53.1**	**471.8**

* Min = Minimum, Max = Maximum

As Figure 3 shows, the times of day during which our participants cycled did not differ much between bicycle and e-bike. The overall patterns appear to be quite similar. More pronounced were differences between the age groups, as especially our older riders exhibited usage patterns that deviated from those of the other two groups. The older riders' cycling activity was concentrated mostly between 8:00 and 17:00, with only slightly more than 10% of cycling outside these hours. Peak usage in this age group occurred, for both bicycle types, around lunchtime (11:00-13:59). In contrast, usage was much more spread out for the two other age groups, with some activity already from 05:00 to 07:59 (presumably work related), and considerable activity occurring at 17:00 and later. This difference between the age groups is also reflected in the trip purposes participants reported prior to participation (Table 5), where older riders of both bicycle and e-bike only reported very few work related trips. What also stands out is that e-bike riders reported a much higher proportion of recreational use compared to riders of conventional bicycles, especially among the older riders.

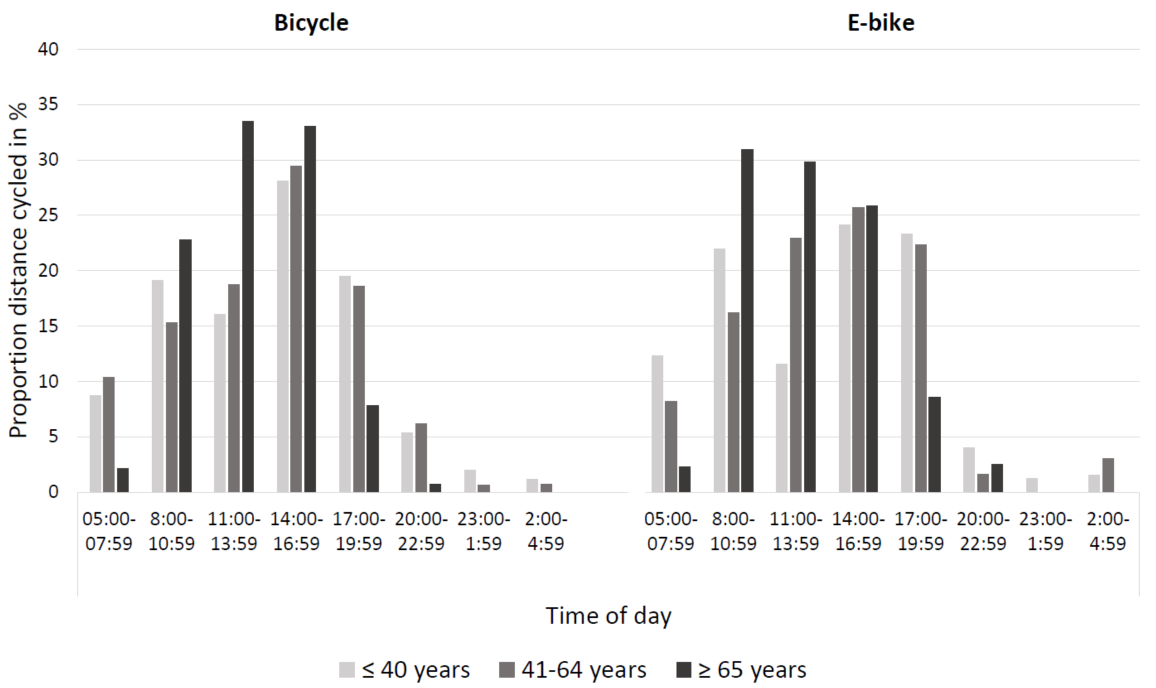

Figure 3: Proportion of total distance cycled during different times of day per bicycle type and age group (*n* = 76)

Table 5: Frequency of bicycle / e-bike use for different trip purposes (reported by participants prior to participation, in % out of 100 % total) for the different age groups (*N* = 80).

	Bicycle				E-bike			
	≤ 40 years	41 - 64 years	≥ 65 years	*Total*	≤ 40 years	41 - 64 years	≥ 65 years	Total

Job / education (e.g. to work, university)	47.7	47.0	3.6	31.8	49.0	33.2	6.8	28.2
Private errand (e.g. shopping, doctor)	34.3	31.2	65.0	44.2	32.2	34,3	42.6	36.8
Recreation (e.g. cycling tour)	18.0	21.8	29.1	23.2	18.8	32.5	50.6	35.0

With regard to operation speed, we found significant differences between the bicycle types (F (1, 64) = 6.91, p = .011, η^2_p = 0.10, Table 6), with a higher mean speed for e-bike riders. In addition, there was a significant effect of age group (F (2, 64) = 11.07, p < .001, η^2_p = 0.26). Post hoc tests (Bonferroni correction for multiple comparisons) showed that the older group (≥ 65 years) was, on average, significantly slower than the younger group (p < .001). There was no difference between the 41-64 years group and the older participants (p = .050) as well as the younger participants (p = .184). We also found a main effect of sex, as male riders were, on average, significantly faster than female ones (F (1, 64) = 12.49, p = .001, η^2_p = 0.16). There was no interaction between any of these factors.

Table 6: Mean speed per bicycle type, age group and sex (n = 76).

	Bicycle (n = 28)				E-bike (n = 48)			
	M	*SD*	*Min*	*Max*	*M*	*SD*	*Min*	*Max*
≤ 40 years	16.6	3.4	13.1	22.0	20.5	5.2	12.9	31.0
41 - 64 years	15.8	2.3	12.6	20.3	17.5	4.0	12.2	25.3
≥ 65 years	13.9	2.6	10.1	18.4	14.8	1.9	12.2	18.6
Male	16.1	3.1	12.1	22.0	18.6	4.9	12.4	31.0
Female	14.0	2.1	10.1	17.5	15.8	3.3	12.2	22.5
Total	**15.3**	**2.9**	**10.1**	**22.0**	**17.4**	**4.4**	**12.2**	**31.0**

3.2 Traffic conflicts

3.2.1 Traffic conflict frequency

In total, we observed 175 traffic conflicts (N = 80; 77 conflicts for bicycle riders, 98 conflicts for e-bike riders). Nearly one-fourth of the participants did not experience a single conflict (19

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participants). Most participants were involved in one to three conflicts (47 participants), and less than one-fourth (14 participants) experienced four or more conflicts. Tables 7 and 8 show the number of traffic conflicts per bicycle type for the different age groups and sexes. Results revealed neither significant main effects for bicycle type ($U(31, 49) = 745.0$, $p = .884$, $d = 0.20$), nor age group ($H(2) = 0.128$, $p = .938$, $d = 0.06$), nor sex ($U(47, 33) = 622.5$, $p = .127$, $d = 0.26$). A similar picture emerged after we corrected for cycled distance (SIR). Again, there were no significant differences between the bicycle types ($U(28, 48) = 622.5$, $p = .592$, $d = 0.22$), age groups ($H(2) = 0.608$, $p = .738$, $d = 0.27$) and sexes ($U(44, 32) = 569.0$, $p = .153$, $d = 0.02$).

Table 7: Number of traffic conflicts per bicycle type and age group.

				Bicycle				
	N	*Total conflicts*	*M*	*SD*	*Median*	*Min*	*Max*	*SIR*
≤ 40 years	10	25	2.50	2.55	1.5	0	7	1.92
41 - 64 years	10	28	2.80	3.46	2.5	0	12	1.19
≥ 65 years	11	24	2.18	2.96	1.0	0	9	1.29
Total	**31**	**77**	**2.48**	**2.92**	**2.0**	**0**	**12**	**1.44**
				E-bike				
	N	*Total conflicts*	*M*	*SD*	*Median*	*Min*	*Max*	*SIR*
≤ 40 years	16	35	2.19	3.02	1.5	0	12	1.26
41 - 64 years	14	26	1.86	1.66	2.0	0	5	1.18
≥ 65 years	19	37	1.95	1.27	2.0	0	4	0.98
Total	**49**	**98**	**2.00**	**2.05**	**2.0**	**0**	**12**	**1.13**

Note: SIR = safety incidence rate: number of traffic conflicts per 100 km travelled

Table 8: Number of traffic conflicts per bicycle type and sex.

				Bicycle				
	N	*Total conflicts*	*M*	*SD*	*Median*	*Min*	*Max*	*SIR*
Male	19	56	2.50	3.33	2.0	0	12	1.38
Female	12	21	2.80	2.05	1.0	0	6	1.52
Total	**31**	**77**	**2.48**	**2.92**	**2.0**	**0**	**12**	**1.44**
				E-bike				
	N	*Total conflicts*	*M*	*SD*	*Median*	*Min*	*Max*	*SIR*
Male	28	57	2.04	1.40	2.0	0	6	1.17
Female	21	41	1.95	2.73	1.0	0	12	1.07

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Total	**49**	**98**	**2.00**	**2.05**	**2.0**	**0**	**12**	**1.13**

Note: SIR = safety incidence rate: number of traffic conflicts per 100 km travelled

Table 9 provides more detail on the observed traffic conflicts, based on the verbal descriptions of the events that were produced during the video review. It becomes clear that the type of conflict differed depending on whether the conflict partner was a motorised road user, another cyclist or a pedestrian. Conflicts with motorised vehicles were often caused by motorists failing to yield. Typical situations included a motorised vehicle turning right and crossing the bike path (apparently) without checking for the rider, or a motorised vehicle failing to yield to a bicyclist approaching from the right. Such situations appeared to be more frequent for e-bikes than for conventional bicycles. The same was true for situations in which a motorised vehicle in some way encroached upon the path of the cyclist. Here, again, the proportion of traffic conflicts was higher for e-bike riders.

In interactions with other cyclists, conflicts often occurred as a result of passing or being passed closely either in the same (overtaking) or opposite direction. In many of these situations, sudden and presumably unexpected braking or swerving manoeuvres of the other cyclist appeared to play a role, especially for riders of conventional bicycles. In interactions between our participants and pedestrians, most conflicts were characterised as crossing situations, e.g. a pedestrian on the pavement that crossed the carriageway or the bicycle infrastructure. A type of situation that was observed rather frequently especially for cyclists involved oncoming pedestrians that encroached upon the path of the participant unexpectedly.

Table 9: Traffic conflicts in detail.

Description of the conflict	Total conflicts Bicycle	% conflicts Bicycle	Total conflicts E-bike	% conflicts E-bike
Conflict with motorised vehicle				
Trajectories of motorised vehicle and participant crossed				
Motorised vehicle failed to yield to participant	9	11.7	17	17.3

Participant failed to yield to motorised vehicle	4	5.2	6	6.1
Parking or turning manoeuvre of motorised vehicle, encroaching upon path of participant	7	9.1	16	16.3
Motorised vehicle and participant travelled in the same direction				
Motorised vehicle closely passed participant	4	5.2	7	7.1
Participant tried to pass stopped/slow motorised vehicle too closely (passing attempt aborted)	2	2.6	1	1.0
Motorised vehicle swerved or suddenly stopped in front of participant	2	2.6	1	1.0
Motorised vehicle and participant travelled in opposite directions				
Motorised vehicle passed another vehicle using path of oncoming participant	3	3.9	4	4.1
Conflict with cyclist(s)				
Trajectories of cyclist(s) and participant crossed, other cyclist(s) unexpectedly crossed path of participant	3	3.9	4	4.1
Cyclist(s) and participant travelled in the same direction, sudden braking or swerving by other cyclist(s) in front of participant	8	10.4	3	3.1
Cyclist(s) and participant travelled in opposite directions, irritation about how to go about passing each other	6	7.8	8	8.2
Conflict with pedestrian(s)				
Trajectories of pedestrian(s) and participant crossed, pedestrian(s) crossed path of participant (e.g. jaywalking)	12	15.6	18	18.4
Pedestrian(s) and participant travelled in the same direction, pedestrian(s) suddenly stopped or moved into path in front of participant	4	5.2	6	6.1
Pedestrian(s) and participant travelled opposite directions, oncoming pedestrian(s) encroached upon path of participant unexpectedly	8	10.4	4	4.1
Conflicts with dogs (unexpectedly encroaching upon path of participant)	5	6.5	3	3.1

3.2.2 Contextual factors

Tables 10, 11 and 12 display the risk of being involved in a traffic conflict for each annotated contextual factor. In each table, OR and corresponding 95% confidence intervals are presented to illustrate the potential impact that the presence of each of the factors might have. In Tables 10 (bicycle conflicts) and 11 (e-bike conflicts), an OR above 1 indicates that a rider of the respective type of bicycle was at a higher risk to be involved in a conflict when the contextual factor was present compared to when the factor was absent. Table 12 provides a direct comparison of the conflict rates for the two bicycle types. The OR is presented from the perspective of the e-bike, i.e. an OR above 1 indicates a higher risk for an e-bike rider than a conventional bicycle rider for involvement in a traffic conflict when the respective contextual factor was present.

When inspecting the OR for the two bicycle types, some clear similarities as well as notable differences stand out. Not surprisingly, the presence of other road users in most cases was associated with a significant increase in the risk of a conflict to occur for both bicycle types. At the same time, the details differ somewhat between bicycle types. For conventional bicycles, the risk increase was strongest in the presence of other vulnerable road users (cyclists, pedestrians), whereas the difference in risk increase between motorised and vulnerable road users was less pronounced for e-bikes. In fact, the direct comparison of the two bicycle types indicates that e-bike riders might be significantly safer around other cyclists than riders of conventional bicycles.

Results for used infrastructure were inconsistent. The direct comparison of bicycle types showed no significant effects. However, some of the infrastructure categories had a significant influence on risk for one of the bicycle types. Cycling on the carriageway reduced risk for conventional bicycles, whereas riding on unpaved paths reduced risk for e-bike riders. Perhaps the most interesting finding is the clear difference in risk between the two bicycle types in the vicinity of intersections. While the risk of being involved in a conflict around various forms of intersections was not higher than elsewhere for conventional bicycles, the risk more than doubled for e-bikes. This result is further underlined by the direct comparison of the bicycle types, with the risk of a conflict around an intersection twice as high for e-bikes as for conventional bicycles.

Road gradient did not appear to influence the risk of traffic conflicts. Although the ORs point towards lower risk when cycling uphill and higher risk when riding downhill, the differences were not statistically significant regardless of bicycle type. High similarities in risk patterns also occurred for specific road surface aspects. For conventional bicycles and e-bikes alike, riding on paving stones increased risk significantly, whereas other potential issues such as poor surface conditions or obstacles did not affect risk substantially. As expected, there was a significant increase in risk for infringements and violations on behalf of the cyclists, however, there were no differences between the two bicycle types. Being overtaken also led to a considerable (however non-significant) risk increase.

Table 10: OR and CI for **bicycle** conflicts for different (categories of) factors (the calculation of prevalence is based on 77 conflicts and 154 baseline events).

	Prevalence in baseline events in %	*Prevalence in conflicts in %*	*OR*	*95% CI*
Other road user				
Vehicle ≤ 3,5t	**27.3**	**42.9**	**2.000**	**1.127 – 3.551**
Car	**26.6**	**42.9**	**2.067**	**1.162 – 3.676**
Cyclist/E-bike rider	**7.1**	**28.6**	**5.200**	**2.365 – 11.432**
Pedestrian	**58.1**	**11.4**	**6.239**	**3.236 – 12.029**
Pedestrian and dog	**12.3**	**49.4**	**6.923**	**3.593 – 13.340**
Used infrastructure				
Carriageway	**61.0**	**39.0**	**.407**	**.233 – .714**
Pavement	10.4	16.9	1.752	.795 – 3.859
Bicycle infrastructure	**24.7**	**41.6**	**2.171**	**1.212 – 3.888**
Unpaved path	4.5	5.2	1.151	.326 – 4.057
Intersection type				
Intersection (all)	43.5	41.6	.923	.531 – 1.607
Intersection with traffic light	14.9	16.9	1.157	.550 – 2.432
Intersection left yields to right/priority sign	22.1	15.6	.652	.316 – 1.344
Road gradient				
Uphill	27.3	15.6	.492	.242 – 1.002
Downhill	15.6	23.4	1.653	.834 – 3.276
Flat	57.1	61.0	1.175	.672 – 2.053

Road surface				
Paving stones	**18.2**	**36.4**	**2.571**	**1.385 – 4.776**
Poor conditions of road surface	28.0	21.9	.722	.373 – 1.395
Obstacle	13.6	13.0	.945	.421 – 2.121
Other factors				
Infringement of traffic regulations	**17.5**	**33.8**	**2.398**	**1.278 – 4.498**
Being overtaken	4.5	10.4	2.435	.849 – 6.985

Note. Significant values printed in bold, OR = Odds Ratio, 95% CI = 95% confidence interval.

Table 11: OR and CI for **e-bike** conflicts for different (categories of) factors (the calculation of prevalence is based on 98 conflicts and 196 baseline events).

	Prevalence in baseline events in %	*Prevalence in conflicts in %*	*OR*	*95% CI*
Other road user				
Vehicle ≤ 3,5t	**26,0**	**57,1**	**3.791**	**2.272 – 6.324**
Car	**24.5**	**51.0**	**3.212**	**1.924 – 5.363**
Cyclist/E-bike rider	17.3	24.5	1.545	.856 – 2.789
Pedestrian	**10.2**	**36.7**	**5.110**	**2.753 – 9.484**
Pedestrian and dog	**12.8**	**36.7**	**3.972**	**2.208 – 7.145**
Used infrastructure				
Carriageway	57.7	58.2	1.021	.625 – 1.669
Pavement	10.7	16.3	1.626	.806 – 3.279
Bicycle infrastructure	19.9	29.6	1.692	.969 – 2.955
Unpaved path	**12.2**	**3.1**	**.226**	**.066 – .771**
Intersection type				
Intersection (all)	**25.0**	**46.9**	**2.654**	**1.591 – 4.427**
Intersection with traffic light	**5.6**	**13.3**	**2.572**	**1.107 – 5.976**
Intersection left yields to right/priority sign	**17.3**	**28.6**	**1.906**	**1.074 – 3.382**
Road gradient				
Uphill	25.5	18.4	.657	.359 – 1.202
Downhill	15.2	22.4	1.541	.837 – 2.836
Flat	58.7	59.2	1.021	.624 – 1.672
Road surface				
Paving stones	**15.3**	**30.6**	**2.441**	**1.368 – 4.358**
Poor conditions of road surface	32.3	23.2	.632	.359 – 1.111
Obstacle	13.8	12.4	.873	.422 – 1.808
Other factors				
Infringement of traffic regulations	**14.3**	**31.6**	**2.776**	**1.548 – 4.979**
Being overtaken	5.1	11.2	2.352	.962 – 5.746

Note. Significant values printed in bold, OR = Odds Ratio, 95% CI = 95% confidence interval.

Table 12: OR and CI for different (categories of) factors for **e-bike vs. bicycle** conflicts (the calculation of prevalence is based on a variable number of conflicts and events for each factor – see columns "Baseline events" and "Conflicts").

	Base-line events	*Prevalence in baseline events in %*	*Conflicts*	*Prevalence in conflicts in %*	*OR*	*95% CI*
Other road user						
Vehicle ≤ 3,5t	93	54,8	89	62,9	1.398	.772 – 2.529
Car	89	53.9	83	60.2	1.294	.706 – 2.372
Cyclist/E-bike rider	**45**	**75.6**	**46**	**52.2**	**.353**	**.145 – .862**
Pedestrian	39	51.3	72	50.0	.950	.436 – 2.071
Pedestrian and dog	44	56.8	74	48.6	.720	.340 – 1.525
Used infrastructure						
Carriageway	207	54.6	78	65.5	1.581	.940 – 2.658
Pavement	37	56.8	29	55.2	.938	.352 – 2.496
Bicycle infrastructure	77	50.6	61	47.5	.883	.451 – 1.730
Unpaved path	31	77.4	7	42.9	.219	.039 – 1.219
Intersection type						
Intersection (all)	**116**	**42.2**	**78**	**59.0**	**1.966**	**1.098 – 3.519**
Intersection with traffic light	34	32.4	26	50.0	2.091	.730 – 5.989
Intersection left yields to right/priority sign	**155**	**50.0**	**51**	**70.0**	**2.333**	**1.021 – 5.333**
Road gradient						
Uphill	92	54.3	30	60.0	1.260	.545 – 2.912
Downhill	55	56.4	40	55.0	.946	.417 – 2.148
Flat	203	56.7	105	55.2	.944	.588 – 1.518
Road surface						
Paving stones	58	51.7	58	51.7	1.000	.483 – 2.072
Poor conditions of road surface	104	59.6	38	58.0	.931	.438 – 1.979
Obstacle	48	56.3	22	54.5	.933	.338 – 2.574
Other factors						
Infringement of traffic regulations	55	51.0	57	54.4	1.150	.547 – 2.416
Being overtaken	17	58.8	19	57.9	.963	.255 – 3.630

Note. Significant values printed in bold, OR = Odds Ratio, 95% CI = 95% confidence interval.

3.2.3 Conflicts and speed

In a final step, we had a look into cycling speed immediately preceding the conflicts. In Table 13, mean speed immediately preceding the conflict is displayed per bicycle type, age group and sex. As can be clearly seen, the pattern is the same as for our participants' general cycling speed (Table 6).

Riders of e-bikes were significantly faster than conventional cyclists, younger riders faster than older ones, and male riders faster than females immediately prior to a traffic conflict. When isolating conflicts at intersections (Table 13), one of the most frequent contexts for conflicts, the same picture emerged.

Table 13: Mean speed per bicycle type, age group and sex for all traffic conflicts and for traffic conflicts at intersections.

	Traffic conflicts						Traffic conflicts at intersections					
	Bicycle			E-bike			Bicycle			E-bike		
	M	*SD*	*Total con-flicts*	*M*	*SD*	*Total con-flicts*	*M*	*SD*	*Total con-flicts*	*M*	*SD*	*Total con-flicts*
≤ 40 years	18.3	4.0	11	19.4	7.4	35	16.2	1.1	2	21.9	9.3	11
41 - 64 years	15.8	6.1	24	17.6	7.3	26	14.1	6.3	12	19.8	7.7	13
≥ 65 years	14.4	5.5	24	14.5	5.1	37	13.1	4.9	12	14.7	5.7	22
Male	15.6	6.2	46	18.3	7.2	57	13.6	5.8	22	19.2	8.7	25
Female	15.9	2.9	13	15.4	6.0	41	14.8	1.8	4	16.3	6.3	21
Total	**15.7**	**5.6**	**59**	**17.1**	**6.8**	**98**	**13.8**	**5.4**	**26**	**17.9**	**7.8**	**46**

4 DISCUSSION AND CONCLUSION

The primary goal of the study presented in this paper was to assess potential differences in cyclists' involvement in traffic conflicts dependent on bicycle type. We found no difference between bicycles and e-bikes in that regard, in absolute terms as well as when correcting for cycled distance. It appeared that at least overall, conflict involvement of conventional bicycles and e-bikes was similar. This finding was somewhat unexpected, given that e-bike riders indeed travelled faster on average than riders of conventional bicycles. We also found a considerable overlap between the risk patterns for the two bicycle types when examining contextual factors. Aspects like certain types of road surface or violations of traffic regulations increased risk for both bicycle types. Likewise, the presence of any other road user, regardless of whether it was a pedestrian, another cyclist, or a motorised vehicle, led to a considerable risk increase. On a descriptive level, odds ratios on the role of other road users support the observation that e-bikes are at increased risk to conflict especially with motorised road users (Dozza et al., in press).

One notable difference between the bicycle types was found for the role of intersections, where the risk for a conflict to arise was significantly higher for e-bikes. This finding is further substantiated by the fact that on a descriptive level, the relative frequency of events in which a motorised road user failed to yield was higher for e-bikes. This is in line with results from experimental studies which report that motorists tend to accept smaller gaps in crossing situations in front of an oncoming e-bike compared to a bicycle approaching at the same speed (Petzoldt et al., in press). This effect was hypothesised to be the result of an apparent mismatch between the cyclist's actual speed and the speed perceived by the motorist. Given that the motorised component eases acceleration for the e-bike rider, it could be expected that misjudgements of e-bike speed are especially prevalent at intersections, resulting in an increased number of conflicts. Additional evidence for this interpretation is the finding that the risk for conventional cyclists to be involved in a traffic conflict with another motorised vehicle present is much lower than with other road users, whereas this difference is much less clear for e-bike riders.

The analysis of the three age groups did not show any differences in conflict involvement. Given the often increased crash rates reported for older riders (Martínez-Ruiz et al., 2014), this might appear somewhat surprising. However, there are multiple factors that can explain this apparent discrepancy. One aspect is the nature of most studies on crash rates, which rely either on crash statistics or hospital data. As, due to age related physical frailty, crash severity is often higher for older cyclists than younger ones, they naturally end up more often in hospital or crash statistics (Oxley, Corben, Fildes, O'Hare, & Rothengatter, 2004). The more serious issue, however, is the fact that older riders have been found especially prone to be involved in single vehicle crashes (Schepers, 2012), a category of events that unfortunately is not covered in our data. While the risk of an older rider being involved in a traffic conflict with another road user appears to be similar to the risk of other age groups, the risk of single vehicle events might still be elevated.

It should be noted that differences in travel patterns certainly have the potential to influence to absolute risk of being involved in traffic conflicts. As our analyses show, the times of the day during which cyclists are on the road as well as the trips they make, differ between age groups as well as bicycle types. Others have found that the exposure toward certain potential risk factors (e.g. intersections) differs between riders of conventional bicycles and e-bikes (Dozza & Piccinini, 2014). While this is not expected to affect the relative risk of a conflict given the presence or absence of a certain risk factor (as the risk factor would not only occur more often in conflict episodes, but also in baselines), it of course has an impact on the actual frequency at which riders experience certain types of conflicts. Still, the findings of our study suggest that, with regard to relative risk, the chance of being involved in a traffic conflict when riding a e-bike is not higher than when riding a conventional bicycle. However, in specific contexts such as intersections, e-bike riders should expect other road users to misjudge the e-bike's speed to prevent potential safety critical situations. It also has to be acknowledged that, since our analysis focussed on pedelecs, the findings reported in this paper might not apply to faster e-bikes such as S-pedelecs. These faster e-bikes currently constitute only a small fraction of the total number of electrically assisted bicycles sold in Europe, however, their potential effects on road safety should not be neglected. While it is expected that increased exposure to e-bikes of various kinds will eventually result in sufficient awareness among other road users, the learning process that is required to achieve this should certainly be supported.

Although the naturalistic cycling approach without doubt provides unparalleled insight into cycling conflicts and their circumstances, the method is not without limitations. As stated before, the fact that single vehicle events, which constitute the majority of hospitalisations (e.g. Schepers, Agerholm, et al., 2014), are difficult to observe, is certainly a drawback. Comparisons between our findings and other datasets that include such single vehicle events should therefore be drawn with caution. In general, is has to be acknowledged that like with every method that relies on video recordings, only what is captured in the video can be analysed. The camera setup used in this study (forward view + upper body) did not allow for a complete coverage of the traffic environment at all time, so there is a chance that certain conflicts might have been overlooked. Insufficient lighting during night time riding and adverse weather conditions might add to that problem (though it should be noted that there was hardly any night time riding in our dataset, as well as only few episodes of riding during bad weather). Another possible issue is the reliance on voluntary participation, which has the potential to bias the subject sample towards experienced and healthy participants. The requirement of frequent use in order to obtain a sufficiently large data set might increase that bias. As it is known that frequent and experienced riders incur a higher crash severity (Cripton et al., 2015; Heesch, Garrard, & Sahlqvist, 2011), it might be assumed that conflict characteristics as observed in our study differ somewhat from the nature of conflicts involving less experienced, infrequent riders. Also, it must be suspected that the groups of conventional cyclists and e-bike riders differed in certain demographic characteristics, as for a cyclist to purchase an e-bike, there must be a certain motivation as well as the economic means to do so. While variables such as income and education can hardly be suspected to impact on a riders' safety record, other aspects such as a reduced physical fitness as a potential reason for the purchase of an e-bike have the potential to influence the characteristics of traffic conflicts that riders encounter. While our broad judgment of our participants stability when cycling provided no evidence for any major issues or differences between the two groups, we cannot rule out that there might have been subtle variations in riding capability that could have influenced their bicycle usage and riding behaviour. At the same time, it should be noted that any differences in these aspects would be merely a reflection of the current user populations of the different types of bicycles.

It is clear that naturalistic cycling data alone cannot answer all questions with regard to cycling safety. Stationary observations, surveys, field tests and experiments are as vital in the pursuit of a comprehensive picture. Nevertheless, the analysis of naturalistic cycling data can play an important role in such a mixed-methods approach, in which it can serve both to complement and validate results obtained through other means, as well as to generate new research questions that might be tested in more controlled environments. Given the rapid technological development, which has made the technology required to conduct such naturalistic studies much more usable and affordable, it is only a matter of time before more large scale naturalistic cycling studies, which will be able to provide much larger and richer datasets, will be conducted.

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