Proceedings, International Cycling Safety Conference 2014
18-19 November 2014, Göteborg, Sweden

Do cyclists on e-bikes behave differently than cyclists on traditional bicycles?

M. Dozza[*], G.F. Bianchi Piccinini[#]

[*]Chalmers University of Technology, Department of Applied Mechanics, Division of Vehicle Safety, Accident Prevention Group
Lindholmspiren 3, 41296, Gothenburg, Sweden
marco.dozza@chalmers.se

[#]Chalmers University of Technology, Department of Applied Mechanics, Division of Vehicle Safety, Accident Prevention Group
Lindholmspiren 3, 41296, Gothenburg, Sweden
giulio.piccinini@chalmers.se

ABSTRACT

Cycling is a healthy, environmentally-friendly and enjoyable activity, which unfortunately also claims more than 2000 lives every year in Europe. Many municipalities across Europe are waging successful campaigns to increase cycling and, as a consequence, reduce pollution and congestion. However, at least in the short term, a surge in cycling is also challenging existing infrastructure, regulations, and the interaction among different road users. Further, the nature of cycling is changing as new electrified bicycles (e-bikes) become more prevalent, since they are able to maintain a constant 25km/h speed independent of road gradient or wind. The extent to which e-bikes prevalence impacts safety is currently unknown and very hard to simulate with statistical models.

In 2012, the BikeSAFE project collected 1474 km of naturalistic cycling data from traditional bicycles. Similarly, in 2013, the e-BikeSAFE project collected 1549 km of naturalistic data from e-bikes. All studies took place in the urban area of Göteborg in the same period of the year, and involved the same participants as much as possible. While these naturalistic data sets are limited and possibly not representative of the cycling situation in all of Europe, they are also the most advanced data available today for comparing how traditional and electrical bicycles behave in traffic, thus offering a promising test bed for developing data analysis methodologies.

Five random video clips of 30 seconds duration were extracted for each participant from the data collected in BikeSAFE and e-BikeSAFE, forming an overall analysis database of 140 full HD video clips. Video reduction identified which road users were involved in interactions with the bikes (traditional or electric). During the analysis, potential influencing factors (e.g. width, gradient, and curvature of the cycle path) were also taken into account. Information from the video reduction of e-bikes and traditional-bikes was compared by means of odds ratios and combined with subjective data from questionnaires, to determine the extent to which safety concerns about e-bikes are legitimate.

Results show that e-bikes and traditional bicycles are ridden differently: cyclists riding e-bikes experience different, more frequent interactions with other road users, and prefer different riding conditions, possibly because of their higher speed. Further, infrastructure (such as crossings) and secondary tasks (such as using a phone) may be particularly dangerous for e-bikers. The results presented in this paper provide new ideas for the design of safer cycle paths and more conspicuous e-bikes.

Keywords: Cycling safety; Electrical bicycles; Naturalistic data; Road Safety; Road user interaction.

1 INTRODUCTION

Cycling is not just a fun activity; it may also be a single solution for multiple societal issues such as pollution, heart disease, increasing transportation costs, and congested urban centers. In Sweden, as in many other countries, the cyclists' community is rapidly growing, which helps solve the issues above but also alters road traffic. Changes in traffic include (1) a different split between cars and bicycles [1, 2, 3] and (2) the increasing prevalence of electrified bicycle-like vehicles, such as electric kickboards, bike boards, and electric bicycles where the rider's pedalling is assisted by a small electric motor (e-bikes). Although both may have important implications for traffic safety, the second type of change has been much less investigated than the first and is the focus of this paper.

E-bikes are particularly prevalent compared to other electrified vehicles that share cycle paths with traditional bicycles in Europe. In fact, e-bike sales in 2012 were between 700,000 and 1,200,000 in Europe, a twofold increase compared to 2009 and an eightfold increase compared to 2006. In fact, e-bike prices are also constantly decreasing, making them increasingly accessible to everyone independent of age or income. Thus e-bikes are rapidly becoming a significant share of the bicycles in traffic. However, to date they are largely unregulated: e-bike riders are not required to have insurance or a license, and there is no age requirement. Basically, e-bikes look like traditional bicycles and are supposed to follow the same regulations. The concept of safety in numbers [4] is reassuring with respect to the increasing number of traditional bicycles, as it is foreseen to actually decrease accident risk. However, the safety-in-numbers concept may not necessarily be applicable to e-bikes. In fact, e-bikes may behave differently than traditional bikes, surprising road users and challenging current infrastructure.

In the past, the evolution of a vehicle propulsion system resulted in sweeping mobility changes, which in turn drastically influenced safety and created new requirements for regulation, education, and infrastructure. In fact, the first motorized vehicles looked like carriages without horses and were not taken seriously until they became increasingly prevalent and revolutionized the overall traffic system. Although e-bikes are not likely to cause the same sort of revolution, they are presently a safety concern in countries where they are already very prevalent [5]. Previous studies show that e-bikes are indeed faster than traditional bicycles [6]. Increased speed alone may cause a different behaviour; however, the extent to which higher average speed translates to higher risk, particularly in terms of interactions with other road users, is still unknown. This paper used naturalistic data from two different studies to investigate possible changes in 1) cycling conditions, 2) road-user interactions, and 3) crossing conditions that e-bikes may exhibit in comparison to traditional bicycles.

2 METHODS

2.1 Participants

The research described in this paper is based on naturalistic cycling data collected in two different studies, one conducted with traditional bicycles and the other one with electric bikes (e-bikes). In both studies, each participant rode an instrumented bicycle (Fig. 1). Overall, 16 participants (26–66 years old; M = 39.1 years, SD = 11.4 years) were included in the first study [7] and 12 participants (22-50 years old; M = 37.6 years, SD = 10.3 years) in the second one [6]. In both studies, there was a perfect split between male and female participants. Despite an effort to keep the same cyclists across the two studies, only six were actually able to participate in both studies. Overall, 1549 km of data were collected from e-bikes and 1474 from traditional bicycles. In both studies, all subjects were initially briefed about the research and signed a consent form. Participants received no specific instructions in terms of mobility patterns; hence, the bicyclists were free to use the traditional or electric bikes according to their preferences. However, the critical and baseline events for traditional and electric bikes occurred in the urban area of Göteborg (see [6] and [7] for a detailed description). This indicates that the participants limited their travel patterns to this region and, therefore, the two studies can be comparable regarding the location for the data collection.

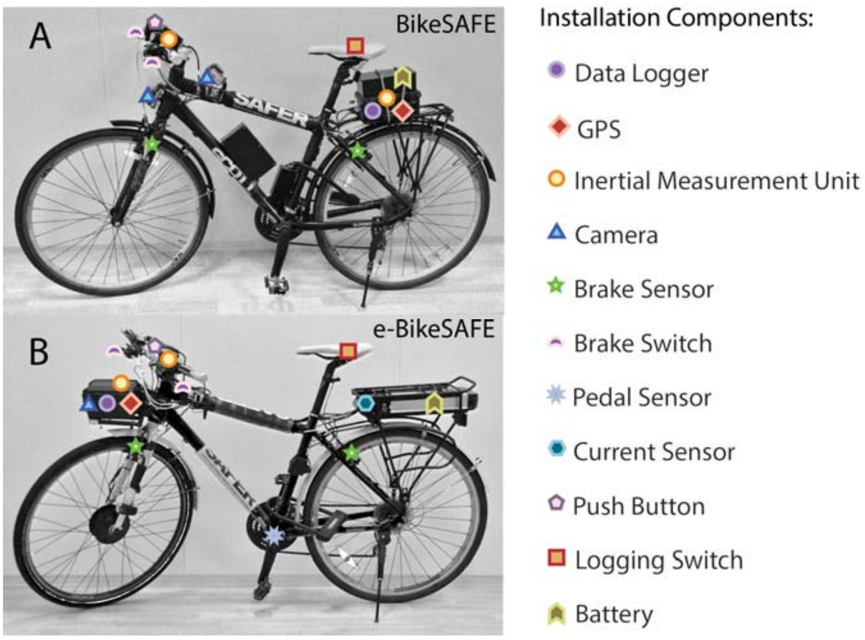

Figure 1: Instrumented bicycles. Installations from the BikeSAFE and e-BikeSAFE project.

2.2 Data collection and procedure

The data collection was performed between August and November 2012 for the traditional bicycles [8] and between August and November 2013 for the electric bikes. E-bikes were equipped with a 250-W electric motor, a control unit, a sensor detecting the rotation of the pedals, two brake switches, a throttle (allowing acceleration up to 6 km/h in accordance with European regulations), and a rechargeable battery on the rear rack. E-bikes were able to maintain a constant 25-km/h speed as long as the pedals kept moving and the bicyclist did not brake, which is the standard way e-bikes work in Europe.

In both studies, each bicycle was equipped with a logger to collect data from the forward video camera (30 fps, full HD) and other sensors. The data collection was completely automatic, starting approximately two minutes after the bicyclist sat on the saddle and stopping after the bicycle had not moved for two minutes, as described in Dozza & Fernandez [8]. In the second study, the logger was powered by the same battery propelling the e-bike. Extra data was also collected from the pedal sensor, the two brake switches, and a current sensor to monitor the operation of the overall system [9].

After all the data in the e-bike study had been collected, the bicyclists filled in a questionnaire including inquiries about the usage of the e-bike (e.g., changes in mobility behaviour, differences compared to a traditional bicycle, behaviour at crossings).

2.3 Data analysis

The data analysis was based on the coding of the video clips from the forward camera, and (in the case of the e-bike study) on the questionnaires filled in by the participants. Odds ratios were used to test whether any difference between e-bikes and traditional bicycles was significant.

For each participant, five 30-s video clips were randomly selected. Given that the video footage from every trip had a different time duration, the selection procedure was performed on the total time ridden and not on the total number of video clips. First, the total time ridden was calculated for each participant. Then, five time indexes were randomly generated from the total time ridden, and the video clips associated with those indexes were selected. A clip was discarded if the bicycle was not moving or, if the bicycle was outside the cycle path for longer than five seconds. We wanted to focus on cycle paths because previous analyses showed that e-bikes are more likely to ride on the road with the traffic than traditional bicycles [6]. Overall, 80 video clips for traditional bicycles and 60 video clips for e-bikes were reviewed and reduced, to enable analysis of: 1) cycling conditions, 2) interactions with other road users, and 3) crossing conditions, according to the categories in Table 1. Cycling conditions are described dichotomously, i.e. values could be true or false. Cyclists' interactions with other road users are described numerically. Similarly, the first three crossing categories, aimed at capturing the conditions at crossings, are also dichotomous; the other three categories, used to analyse the interactions with other road users at crossings, are numerical. During the coding, the possible interactions were classified based on the relative direction of travel of the road users involved, as follows: 'same direction', 'opposite direction' and 'crossing' (Table 1). A similar classification for conflicts has already been used by [10] to determine their severity through the DOCTOR conflict-observation method.

For the e-bike study, the naturalistic data was complemented with subjective information from a questionnaire. The questionnaire, administered to the participants after data collection, provided information about their opinions regarding the usage of the e-bikes (e.g. changes in mobility patterns, interaction with other road users, differences compared to a traditional bicycle, behaviour at crossings).

Odds ratios (OR) were used to estimate whether the prevalence of a category was different between the e-bike and traditional bicycle datasets. OR significance was tested by computing the confidence intervals (CI; 95% probability) and then checking whether the value 1 was included or not in the CI. For the questionnaire data, descriptive statistics were used to combine the answers provided by the participants.

Table 1. Categories for video reduction.

Category		**Description**
Cycling conditions	Asphalted cycle path	Whether the cycle path surface was asphalted or more roughly paved (with cobblestones, cement bricks, etc…).
	Wide cycle path (>1.5 m)	Whether or not the cycle path was wider than 1.5 m.
	Non-flat cycle path	Whether or not the cycle path was flat.
	- Cycle path uphill	Whether or not the cycle path was uphill.
	- Cycle path downhill	Whether or not the cycle path was downhill.
	Coming to a crossing in the first 30s of the video clip	Whether or not a crossing was present in the 30-s video clip.
Interaction with other road users	Pedestrians overtaken (coming from same direction)	Number of pedestrians overtaken in the 30-s video clip.
	Cyclists overtaken (coming from same direction)	Number of cyclists overtaken in the 30-s video clip.
	Pedestrians met (coming from the opposite direction)	Number of oncoming pedestrians met in the 30-s video clip.
	Cyclists met (coming from	Number of oncoming cyclists met in the 30-s

	the opposite direction)	video clip.
Crossing conditions	Crossing	Whether or not the bike crossed a road (intersection) or driveway (e.g. exit from a parking lot).
	Traffic light presence	Whether or not the crossing was a signalized intersection.
	Cross on red light	Whether or not the cyclist crossed the intersection despite the red light.
	Pedestrians crossing	Number of pedestrians crossing the bicycle path when the cyclist reached the crossing.
	Cyclists crossing	Number of cyclists crossing the bicycle path when the cyclist reached the crossing.
	Motorized vehicles crossing	Number of motorized crossing the bicycle path when the cyclist reached the crossing.

3 RESULTS

This section comprises two parts, results from objective data followed by results from subjective data. Each part is organized by the main objectives of the analysis: 1) cycling conditions, 2) interaction with other road users, and 3) crossings. The objective data result from a between-subjects design (comparison between e-bikes and traditional bikes based on two groups of participants) whereas the subjective data originate from a within-subjects design (comparison between e-bikes and traditional bikes based on questionnaires administered only to the participants of the e-bikes study).

3.1 Results from Objective Data

Cycling conditions

Video reduction highlighted that while traditional bicycles rode on non-asphalted (e.g. paved with cobblestone, cement bricks, etc…) cycle paths 10% of the time, e-bikes never did. In addition to choosing the smoother, asphalted cycle paths, e-bike riders also preferred wider cycle paths, a result which was statistically significant (Table 2). Cyclists riding e-bikes were also less concerned about slopes; however, this result was not statistically significant (Table 2). E-bikes crossed other roads more often than traditional bicycles, and this result was statistically significant (Table 2).

Table 2. Cycling conditions.

	e-Bikes	Traditional bicycles	Odds Ratio (95% Confidence Interval)
Asphalted cycle path	100%	90%	NA
Wide cycle path (>1.5 m)	65%	43%	2.9 (1.4-6.0)*
Non-flat cycle path	17%	9%	2.1 (0.7-5.8)
- Cycle path uphill	7%	5%	-
- Cycle path downhill	10%	4%	-
Coming to a crossing in the first 30s of the video clip	58%	40%	2.1 (1.1-4.1)*

* indicates statistical significance of the OR, as the value 1 is outside the confidence interval.

Interaction with other road users

E-bike riders interacted with more cyclists and pedestrians than traditional bicycle riders did. Depending on whether the pedestrians and cyclists came from the same or the opposite direction, interaction required a passing or a meeting manoeuvre from the instrumented bicycle rider (Table 3). Statistics presented in the fourth column of Table 3 prove that all interactions (except those with cyclists traveling in the same direction) are indeed statistically significantly higher for electric bicycles than traditional ones.

Table 3. Interactions with other road users.

	e-Bikes	**Traditional bicycles**	**Odds Ratio (95% Confidence Interval)**
Pedestrians overtaken (coming from same direction)	41	13	11.1 (5.0-24.9)*
Cyclists overtaken (coming from same direction)	10	7	2.1 (0.7-5.8)
Pedestrians met (coming from opposite direction)	42	33	3.3 (1.6-6.8)*
Cyclists met (coming from opposite direction)	39	33	2.6 (1.3-5.3)*

Crossing conditions

Although e-bikes crossed more main roads, approached more intersections when the light was green and went through fewer intersections when the light was red, none of these differences was statistically significant. It is worth noting that only 31 events in total (including both electrical and traditional bicycles) presented a signalized intersection. As a result, interactions with other road users at intersections were too few to enable statistics.

3.2 Results from Subjective Data

In this section, the results are based on the answers obtained from the 12 cyclists that participated in the e-bike study. All results are presented in percentage.

Cycling conditions

According to the e-bike questionnaire, 75% of the cyclists stated that the e-bike changed their mobility behaviour (Fig. 2A) in the following ways: 1) riding more uphill (34.8%), 2) riding even when there was a strong wind or generally bad weather (26.1%), and 3) traveling longer distances (21.7%; Fig. 2B).

Interactions with other road users

75% of the cyclists reported overtaking more bicyclists when riding an e-bike than when riding a traditional bicycle (Fig. 2C), and 83% of the participants recognized that riding an electric bicycle requires more attention compared to a traditional bicycle. The same number of participants also lamented that sharing the path with pedestrians is uncomfortable (Fig. 2D and 2E). Only 33% of the participants thought that the fact that an e-bike is silent is not a problem for other road users (Fig 2F).

Crossing conditions

All riders reported that navigating an intersection with an electrical bike was different than with a traditional bicycle (25% from a very small to a small extent, and 75% from a moderate to a very high extent; Fig. 2G). Half of the cyclists felt that other road users underestimated their speed at intersections, and 33% reported that other road users were not aware of them (Fig. 2H and 2I). At signalled intersections, 58% of the cyclists stated that they sped up when the light switched from green to yellow in order to avoid stopping at the red light (Fig. 2J). Describing their experiences at intersections, one cyclist felt unstable (Fig. 2K), and 17% of them felt the e-bike was hard to manoeuvre. In fact, 42% of the cyclists lamented that it was hard to get started after having stopped at an intersection (Fig. 2L).

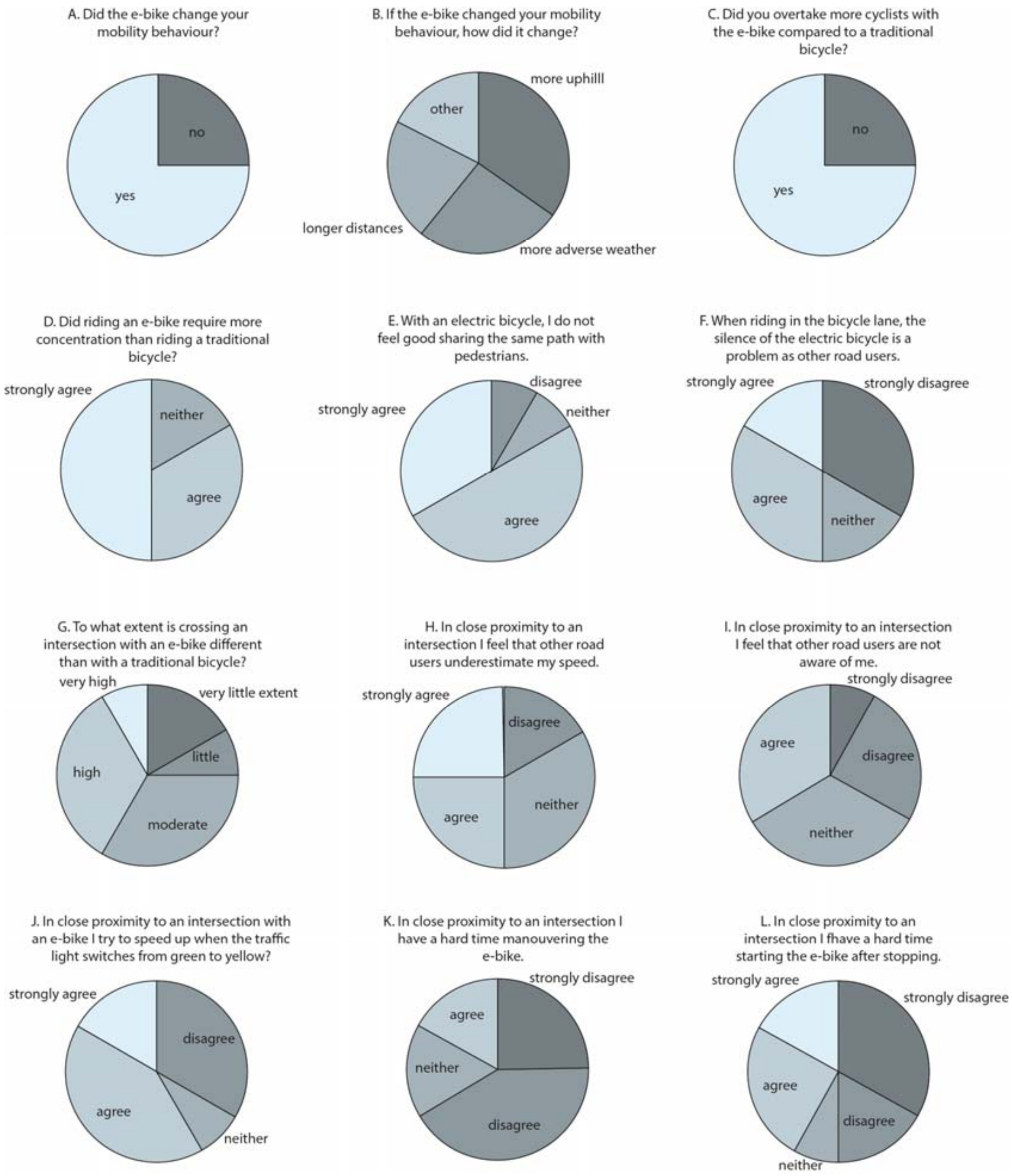

Figure 2. Results from subjective data.

4. DISCUSSION

The ambition of this paper is to determine how e-bikes change riding behaviour and the consequential implications for traffic safety. This study combined subjective and objective data to help control for 1) the limitations that naturalistic data intrinsically present (geography limitations, demographic constraints, etc.) and 2) the biases that a comparison across datasets may induce. Because the number of e-bikes is rapidly increasing, results from this research can guide policy-makers, educators, and road authorities to better prepare for these new vehicles and prevent unforeseen safety issues attributable to shortcoming of the current regulations, training, and infrastructure.

Our results clearly show that e-bikes influence cyclist behaviour and intensify interactions among road users. Further, the results also suggest that crossings are very critical situations where e-bikers' behaviour may have important safety implications. This section outlines the safety impact of their behaviour and describes preventive safety measures which may be put in place to better absorb the increasing number of electrical bicycles in traffic.

4.1 Safety implications of changes in cycling conditions

E-bikers preferred asphalted and extra-wide cycle paths, suggesting e-bikers look for more space for manoeuvring and a smoother ride. This result is in line with our previous observation that e-bikes are faster and ride more on the road with traffic than traditional bicycles do [6], since, in Göteborg, roads are wider and smoother than cycle paths. The higher speed of e-bikes may explain this result, as wider cycle paths and smoother surfaces can increase riding comfort at higher speed. Larger cycle paths also facilitate the interaction with other road users, by providing more room for manoeuvres such as overtaking and meeting.

These differences in mobility behaviour can also be interpreted in terms of self-regulation [11]. Riders, as well as other road users, choose a path depending on their perception of safety [12]. In this study, riders may have simply chosen infrastructure which allowed them to be safe and comfortable, even at higher speeds. To increase safety and facilitate e-bikers, infrastructure could boost this self-regulating behaviour, providing more space for manoeuvring and smoother pavement. Specifically, paving a cycle path differently when it is shared by pedestrians and cyclists may be a better solution than painting a dividing line, which is the most common solution adopted in Sweden. For instance, wider cycle paths could allow for multiple surfaces: cement bricks could pave the pedestrian side, and asphalt the cyclist side. Wider cycle paths could also dedicate more space to cyclists, to compensate for faster manoeuvring. This solution would naturally attract faster cyclists to the asphalted, wider path, possibly decreasing conflict with pedestrians and other road users. This is particularly important, as multi-use paths are not as safe as they have been perceived to be [13]. In specific locations, where infrastructure changes are not a viable solution, regulating bicycle speeds or recommending that e-bikes use the road instead of the cycle path may increase safety.

Subjective data also support the conclusion that cyclists riding e-bikes exhibit a different mobility behaviour; most of the cyclists reported that their mobility behaviour changed. Cyclists further reported that e-bikes helped them ride longer distances, more uphill, and even when weather was bad. These findings suggest that e-bikes may increase individual cycling exposure and change traffic density in safety-critical areas (such as small hills, where visibility is an issue) as well as at safety-critical times (as bad weather also creates visibility and surface-friction issues). Conditions such as these, when safety is at stake, should be prioritized in the development of countermeasures to bicycle accidents.

Objective data corroborates the questionnaire results about increased prevalence of gradients by showing that e-bikes rode uphill or downhill more often than traditional bicycles. This result clearly indicates that slope became less of a concern in route planning for e-bike riders. The ratio between the number of events where a bike was going uphill and events where a bike was going downhill was higher than one for traditional bicycles and lower for e-bikes, although this difference may just be a consequence of speed. In fact, traditional bicycles spend more time riding uphill than downhill (where their velocity is higher). E-bikes may actually spend slightly more time going downhill than uphill, since riding downhill does not require pedalling and may result in a speed lower than 25 km/h. Thus e-bikes may exhibit a markedly different behaviour on slopes than traditional bicycles. In any case, a natural way to encourage e-bikes over traditional bicycles to take a specific path is to design cycle paths with more frequent changes in elevation. For instance, when augmenting capacity of the current infrastructure, offering an alternative cycle path that is wider and presents periodic slope changes may be a better solution than simply widening the current cycle path. The faster e-bikes will tend to take the new route, decreasing conflicts with slower road users.

4.2 Safety implications of changes in interactions with other road users

E-bikes encountered more crossings than traditional bicycles, and their higher speed can explain why. This is even more evidence that e-bikes experience more interactions with other road users than traditional bicycles do. The result that overtaking and meeting manoeuvres with pedestrians and other cyclists are more intense for e-bikes than traditional bicycles contributes to the more complex interactions that e-bikes have with other road users. Previous research shows how critical the interaction among road users is in terms of safety (e.g. [14]) and reaction time (e.g. [15], [16]). Faster interactions with other road users translate to shorter time for anticipation (decision-making such as route planning) and reaction (bicycle control in response to unexpected events), requiring more continuous attention by cyclists on e-bikes. As distraction from cell phones is already a concern for traditional bicycles [17], regulations and education about the use of handheld devices should take into account the likelihood that for e-bikes this activity can be particularly dangerous. Interestingly, manual tasks like SMS writing and more cognitively demanding tasks such as talking on the phone may be equally risky for bicyclists. The tunnel vision induced by talking on the phone [18] may be more detrimental to cyclists' safety than that of drivers, since the former rely more on peripheral information. Furthermore, steering reactions may be impaired by having only one hand on the handlebar.

4.3 Safety implications at crossings

E-bikes had more interactions with other road users in part because they made more crossings of roads/driveways, most likely as a consequence of the higher speed rather than because of route choice. Again, this result evidences the fact that critical situations must be resolved in a shorter time when riding an e-bike. Crossings are particularly important for cyclists, as about 40% of cyclist deaths happen in proximity to an intersection [19]. Lack of conspicuity of e-bikes also appears to be a problem, as cyclists reported feeling unseen; this is important because it highlights the increased demand that interactions with e-bikes impose on other road-users. E-cyclists are aware that they have less time to resolve conflicts with other road users than traditional cyclists. However, while the other road users involved in the conflict also have less time, they may not be aware of the e-bike dynamics, and as a result may not have accurate expectations and responses to the conflict. Conspicuity is important for traditional cycling safety [20], and it may be even more so for e-bikes, which currently look like normal bicycles but behave differently. Unfortunately, bikers seem to overestimate their conspicuity, especially at night, as well as underestimating the effect of devices to increase their conspicuity [21]. Thus, new regulations and education should help increase e-bike conspicuity, for instance by requiring/recommending that lights be on at all times, or that special colours/markers or noticeable features be added to e-bikes.

4.4 Methodological considerations and future research

A clear limitation of this research is the results of combining a between subjects design with a within-subjects design. A fully repeated measures mixed design study (with the same participants taking part in both studies) would have yielded to more robust results. Regarding the questionnaire, in future research, it would be interesting to pose questions similar to the ones listed in section 3.2 to the users of traditional bikes to better understand their perceptions on both traditional and electric bikes. As well, questionnaires with a wider sample will be required for the study of the behaviour, the travel patterns and the opinions of e-bike users. Finally, it is relevant to underline that the present study focused exclusively on pedelec but other types of e-bikes exist (e.g. S-PEDELEC).

Video analysis of crossings provided very few statistically significant results, mainly because the sample was too small. Our results suggest that this analysis is promising and the methodology sound, but at least ten times as many clips are necessary to reach statistical significance. Video reduction is very time-consuming; for this paper it required more than 40 hours. Future studies would definitely benefit from applying this study's methodology to a larger sample; however, unless automatic video processing becomes available [22], the cost of such an analysis may be prohibitive.

Naturalistic data is intrinsically biased by all environmental changes taking place during collection [23]. When two naturalistic data sets are compared, as in this study, possible new biases come into play, raising concerns about the legitimacy of the comparison. Biases may come from the participants, who were not precisely the same across the two data sets (and those who were the same were one year older for the e-bike study), from the weather, and from any other possible seasonal factors. For instance, we measured e-bike speed in 2013 [9], and traditional bicycle speed in 2012 [7]. We assume that the speed of traditional bicycles has not changed in the intervening year. This assumption appears reasonable, mainly because the alternative would be quite complicated, but it cannot be proven with our data. Nevertheless, every time results from subjective data and objective data match, a more confident interpretation of the results can be made. This study tried to include subjective data as much as possible, to prove that the changes between traditional bicycles and e-bikes were actually consequences of changes in the cyclists' behaviour, not just consequences of the environment. Future studies, collecting data from traditional and e-bikes simultaneously, may in part overcome the limitations of this study; however, the cost of such a study would be quite high, and some biases would remain. Including new data in the analysis to normalize and control for possible biases may be a more viable way to increase the accuracy of naturalistic data analysis. For instance, weather data may be used to determine whether temperature and precipitation were similar across the data sets. In conclusion, integration of different data sources may be a more affordable solution to the complexity of naturalistic data then simply trying to increase the data set size.

5. CONCLUSIONS

New mobility behaviours can be expected from the rising community of e-bikers. E-bikes may become more prevalent in critical areas (e.g. small hills) and critical periods (e.g. while raining) with limited visibility. Possibly as a consequence of their higher speed, e-bikers interact more quickly and frequently with other road users than traditional bicyclists. Thus being attentive and predictable is especially important for e-bikers. Correspondingly, distraction may be particularly dangerous for e-bikers, and become even more so if e-bikes' top speed increases in the future. Crossings, where interactions with motorized vehicles are more frequent, seem especially critical.

The results presented in this paper suggest that designing wider cycle paths with smooth asphalt will attract e-bikers, and narrow cycle paths with cobblestone will repel them. Thus, distinguishing the cycle path from the sidewalk by using different pavement surfaces (as opposed to painting a line) may minimize conflicts between pedestrians and cyclists. Increasing e-bikes' conspicuity could enhance anticipation, which would favour interactions among road users and help prevent conflicts. For instance, mandatory lights on at all times or special colours may help other road users be prepared to interact with an e-bike, which today looks like a traditional one although it behaves differently.

This is the first study that combines naturalistic data sets to address cycling safety. This innovative methodology, however, suffers from the intrinsic limitations of naturalistic data and the possible biases that a comparison among data sets may create. Nevertheless, this study combines subjective and objective data to address, at least in part, these methodological concerns.

Future studies may not only leverage larger data sets, but also integrate other data sources to control for possible environmental biases.

ACKNOWLEDGMENTS

The authors would like to acknowledge Alessandro Paoltroni, University of Bologna, for video reduction, Julia Werneke, Michael Mackenzie, and Andre Fernandez for helping with the data collection, and Kristina Mayberry for language revisions. Collection of data presented in this study was supported by Trafikverket, Vinnova, and SAFER. This study was sponsored by Trafikverket and Chalmers Strategic Funds for Transportation and performed at SAFER: Vehicle and Safety Center at Chalmers.

REFERENCES

[1] Elvik, R., "The non-linearity of risk and the promotion of environmentally sustainable transport", *Accident Analysis and Prevention* **41** (2009), pp. 849-855.

[2] Johnson, M., Oxley, J., Newstead, S., & Charlton, J., "Safety in numbers? Investigating Australian driver behaviour, knowledge and attitudes towards cyclists", *Accident Analysis and Prevention* **70** (2014), pp. 148-154.

[3] Schepers, J. P., & Heinen, E., "How does a modal shift from short car trips to cycling affect road safety?", *Accident Analysis and Prevention* **50** (2013), pp. 1118-1127.

[4] Jacobsen, P. L., "Safety in numbers: more walkers and bicyclists, safer walking and bicycling", *Injury Prevention* **9** (2003), pp. 205-209.

[5] Feng, Z. Y., Raghuwanshi, R. P., Xu, Z. G., Huang, D. Y., Zhang, C., & Jin, T., "Electric-bicycle-related injury: a rising traffic injury burden in China", *Injury Prevention* **16** (2010), pp. 417-419.

[6] Dozza, M., Bianchi Piccinini, G.F., & Werneke, J., "Using naturalistic data to assess electric bicycle safety", Submitted to *Transportation Research Part F: Traffic Psychology and Behaviour* on 30/06/2014.

[7] Dozza, M., & Werneke, J., "Introducing naturalistic cycling data: What factors influence bicyclists' safety in the real world?", *Transportation Research Part F-Traffic Psychology and Behaviour* **24** (2014), pp. 83-91.

[8] Dozza, M., & Fernandez, A., "Understanding Bicycle Dynamics and Cyclist Behavior from Naturalistic Field Data", *Ieee Transactions on Intelligent Transportation Systems*, (accepted for publication in 2013).

[9] Dozza, M., Mackenzie, M., & Werneke, J., "e-BikeSAFE: A Naturalistic Cycling Study to Understand how Electrical Bicycles Change Cycling Behaviour and Influence Safety", in *International Cycling Safety Conference*, 20-21 November 2013, Helmond, Netherland.

[10] van der Horst, A. R. A., de Goede, M., de Hair-Buijssen, S., & Methorst, R., "Traffic conflicts on bicycle paths: A systematic observation of behaviour from video", *Accident Analysis & Prevention* **62** (2014), pp. 358-368.

[11] Young, K. L., & Lenné, M. G., "Driver engagement in distracting activities and the strategies used to minimise risk", *Safety Science* **48** (2010), pp. 326-332.

[12] Winters, M., Davidson, G., Kao, D. N., & Teschke, K., "Motivators and deterrents of bicycling: comparing influences on decisions to ride", *Transportation* **38** (2011), pp. 153-168.

[13] Winters, M., Babul, S., Becker, H. J. E. H., Brubacher, J. R., Chipman, M., Cripton, P., Cusimano, M. D., Friedman, S. M., Harris, M. A., Hunte, G., Monro, M., Reynolds, C. C. O., Shen, H., & Teschke, K., “Safe Cycling: How Do Risk Perceptions Compare With Observed Risk?”, *Canadian Journal of Public Health-Revue Canadienne De Sante Publique* **103** (2012), pp. S42-S47.

[14] Räsänen, M., & Summala, H., “Attention and expectation problems in bicycle-car collisions: An in-depth study”, *Accident Analysis and Prevention*, **30** (1998), pp. 657-666.

[15] Summala, H., “Brake Reaction Times and Driver Behavior Analysis”, *Transportation Human Factors*, **2** (2000), pp. 217-226.

[16] Dozza, M., “What factors influence drivers' response time for evasive maneuvers in real traffic?” *Accident Analysis & Prevention* **58** (2013), pp. 299-308.

[17] De Waard, D., Lewis-Evans, B., Jelijs, B., Tucha, O., & Brookhuis, K., “The effects of operating a touch screen smartphone and other common activities performed while bicycling on cycling behaviour”, *Transportation Research Part F-Traffic Psychology and Behaviour* **22** (2014), pp. 196-206.

[18] Trent, V., Dozza, M., "Timing Matters: Visual behaviour and crash risk in the 100-car on-line data", in P*roceedings of the Driver Distraction and Inattention International Conference, Göteborg,* 5-7 September 2011, Göteborg, Sweden.

[19] DaCoTa-Project, *Traffic Safety Basic Facts 2012 - Cyclists*. In E. R. S. Observatory (Ed.), Traffic Safety Basic Facts (2012).

[20] Wood, J. M., Tyrrell, R. A., Marszalek, R., Lacherez, P., Carberry, T., & Chu, B. S., "Using reflective clothing to enhance the conspicuity of bicyclists at night", *Accident Analysis and Prevention* **45** (2012), pp. 726-730.

[21] Wood, J. M., Tyrrell, R. A., Marszalek, R., Lacherez, P., & Carberry, T., "Bicyclists overestimate their own night-time conspicuity and underestimate the benefits of retroreflective markers on the moveable joints", *Accident Analysis and Prevention* **55** (2013), pp. 48-53.

[22] Dozza, M., & González, N. P., "Recognising safety critical events: Can automatic video processing improve naturalistic data analyses?" *Accident Analysis & Prevention* **60** (2013), pp. 298-304.

[23] FESTA-consortium, *FESTA handbook* (http://www.its.leeds.ac.uk/festa/downloads.php) accessed Oct 2012, 2007.

[24] Wood, J. M., Tyrrell, R. A., Marszalek, R., Lacherez, P., Carberry, T., & Chu, B. S., "Using reflective clothing to enhance the conspicuity of bicyclists at night", *Accident Analysis and Prevention* **45** (2012), pp 726-730.