E-bike safety. A review of Empirical European and North American Studies

A white paper prepared for PeopleForBikes

by

Christopher R. Cherry
Department of Civil and Env. Engineering
University of Tennessee
321 John D. Tickle Building, Knoxville, TN 37995-2313, USA
email: cherry@utk.edu

John H. MacArthur
Transportation Research and Education Center
Portland State University
1900 SW Fourth Ave., Suite 175, Portland, OR 97207
email: macarthur@pdx.edu

October 15, 2019

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Portland State UNIVERSITY

LEVER
Light Electric Vehicle Education + Research Initiative

1. Introduction

Electric bikes (e-bikes) are emerging in the United States and Europe as an important complement to conventional bicycles and have already made major inroads into Europe's active transportation systems. E-bikes operate much like conventional bicycles but have a small electric motor to assist the rider, with a few different types of control systems. Most bicycle manufacturers (OEMs) have developed e-bike lines in the past couple of years. In the United States, e-bikes are governed for sale by the Consumer Product Safety Commission (CPSC), but are regulated by use at local and state levels (e.g., how they are regulated on shared use paths) (Macarthur and Kobel 2014). Safety and user conflicts is the primary concern regarding an e-bike's use in the transportation system. In recent years, an evidence-base has begun to emerge from European and North American empirical studies of naturalistic behavior, crash records, hospitalization records, and qualitative safety perception research. This white paper will review and synthesize the recent and emerging research on e-bike safety to explore existing safety evidence that shows the differences in e-bike safety outcomes compared to bicycles, such that differential in treatments (e.g., regulations and insurance) are justified or not. This work will also explore the published evidence on differences between the two predominant classes of e-bikes, Class 1 e-bikes and Class 3 e-bikes.

This report focuses almost exclusively on objectively observed safety information and data, including records of safety proxies and crash or injury reports. The observed data is generally drawn from empirical studies of "naturalistic" rider behavior studies. Naturalistic studies tend to be experiments where bicycle and e-bike riders are observed, usually with onboard sensors, riding during natural day-to-day riding conditions. These instrumented bicycles and e-bikes measure rider behavior during these trips and, depending on the sensors, the researcher can quantify riding behaviors or the behaviors of other street users. These behaviors (e.g., hard braking behavior) can be a proxy for safety outcomes. The other set of studies examine limited crash-oriented data. These datasets are drawn from two sources. First, police crash data is sometimes available when there is a collision with a car. Second, hospitalization data can be extracted and analyzed in the context of injuries while riding an e-bike or bicycle. One other study scrutinizes self-reported crashes. The sources reported in this white paper are drawn primarily from peer-reviewed journal articles. Supplemental literature from credible research reports without evident bias is also drawn from. Most of the sources are reported in the English language, with some Dutch language reports included. All of these data sources may have limitations, such as small sample size and geographic sensitivity.

There is no definitive answer regarding whether e-bikes are more or less safe than conventional bicycling, and under which circumstances. However, there is some evidence of comparisons between e-bikes and conventional bikes in different contexts. This report will limit its analysis to U.S. and European-based studies. There is a heavy representation of e-bike safety studies from the Netherlands, Switzerland, Norway, Germany, and Israel, in part because of available injury reporting data. Figure 1 shows the U.S. and the five largest European markets. This report will exclude studies from other geographies, specifically China-oriented studies because the e-bikes are fundamentally different in form and performance, and cultural and on-road conditions in China are difficult to compare with western traffic safety norms. This report also excludes studies that focus on safety perception of riders, generally drawn from surveys.

This report is organized as follows. First a brief background of the Class-based e-bike regulatory system is described. Next, a series of studies is summarized on e-bike injury analysis from crash and injury datasets. Then a section describes surrogate safety measures drawn from naturalistic studies along with speed measurement studies. The last section concludes with a summary and policy recommendations.

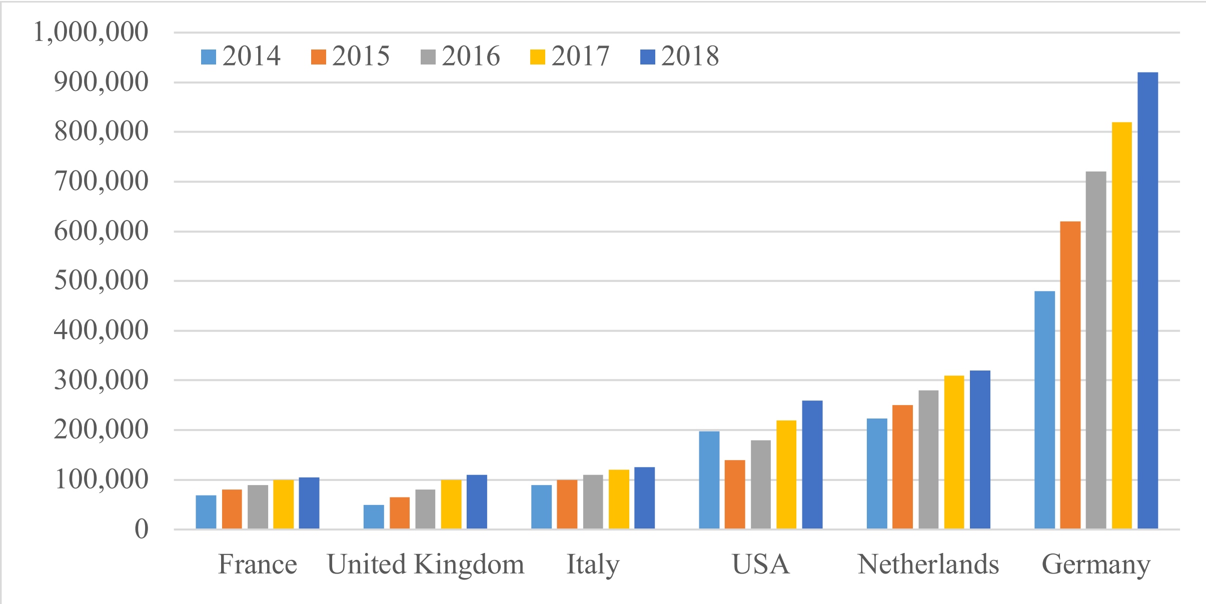

Figure 1
Estimated Sales of E-bikes in the Five Largest European E-bike Markets and the U.S.
Source: Derived from the Electric Bike Worldwide Report, 2016

2. Background

E-bikes are bicycles with functional pedals and a small motor in the hub of the front or rear wheel (i.e., hub motor) or integrated into the crank of the bike near the pedals (i.e., mid-drive motor). All contemporary e-bikes have an on-board lithium-ion battery pack that can often be charged on the bike or removed and charged off of the bike. In the U.S., sales of e-bikes are governed by the Consumer Product Safety Commission (CPSC) as bicycles with fully operable pedals, motor power less than 750 watts, that travel less than 20 mph solely under motor power. This definition allows e-bikes that can travel above 20 mph under motor power if the rider is actively pedaling. Since, the CPSC does not regulate use of e-bikes, many states have adopted a three-class system supported by PeopleForBikes and the Bicycle Products Supplier Association (BPSA).

The U.S. model definitions that have been adopted by the BPSA, along with PeopleForBikes, were developed around a three-class system for e-bikes that is making its way into state legislation. As of August 2019, 22 states have adopted the model legislation. The simple system is distinguished primarily by speed and pedal assistance.

- Class 1: Pedal assist only, maximum assisted speed 20 mph (32 km/hr)
- Class 2: Throttle controlled, maximum assisted speed 20 mph (32 km/hr)
- Class 3: Pedal assist only, maximum assisted speed 28 mph (45 km/hr)

	VEHICLE		USER				BIKEWAY ACCESS			
VEHICLE TYPE	PEDAL OPERATED	MAXIMUM MOTOR-ASSISTED SPEED (MPH)	MINIMUM AGE (YEARS)	DRIVER'S LICENSE	LICENSE PLATE	HELMET	CLASS I BIKE PATH	CLASS II BIKE LANE	CLASS III BIKE ROUTE	CLASS IV PROTECTED LANE
BICYCLE	YES	N/A	N/A	NO	NO	17 AND UNDER	YES	YES	YES	YES
TYPE 1 E-BIKE	YES	20	N/A	NO	NO	17 AND UNDER	YES	YES	YES	YES
TYPE 2 E-BIKE	NO	20	N/A	NO	NO	17 AND UNDER	YES	YES	YES	YES
TYPE 3 E-BIKE	YES	28	16	NO	NO	YES	NO	YES	YES	NO
MOPED	NO	N/A	16	YES	YES	YES	NO	YES	YES	NO

Figure 2
Model Class-based E-bike Definitions Endorsed by E-bike Companies and Advocates

Source: Derived from People for Bikes, 2015 (People for Bikes 2015)

The model legislation enables the definition of a "speed pedelec", a Class 3 e-bike that has different rules on where it can be ridden (e.g., not on shared use paths). This is similar to Europe's type-approval approach, placing Class 3 e-bikes in a different category (L1e-b). Notably, pedal assistance technology or assistance levels is not prescribed in typical legislation prior to the class system. To complicate matters, some e-bikes have both pedal assistance, like Class 1, but can switch modes and be throttle controlled (Class 2), making their inclusion into the legal and practical bicycle definition more challenging.

In Europe, e-bikes fall primarily into Class 1 and Class 3 categories. The most common category is a low-speed pedal assist electric bicycle. The maximum *assisted* speed of European low speed e-bikes is 25 km/hr, 7 km/hr slower than the U.S. Class 1 counterpart. The maximum *assisted* speed of a "speed pedelec" is 45 km/hr, the same as a Class 3 e-bike in the U.S. Where possible, this review will distinguish between Class 1 and Class 3 e-bikes, though most safety reporting does not make such a distinction.

3. Results

Crash and Injury Data

E-bikes are difficult to classify within crash or injury databases. Often, they are classified as either powered-two-wheelers or conventional bicycles. In some cases, e-bikes are categorized specifically or described in the narratives of the reports. There is an ongoing effort to classify motorized "micromobility" vehicles in standardized injury reporting mechanisms. One effort is to modify the ICD-10 codes to explicitly include e-bikes and e-scooters in late 2020.

U.S. Studies

A very recent work tracked powered two-wheeler (e.g., e-bike) injuries through the National Electronic Injury Surveillance System (NEISS) and found that there has indeed been a large increase in injuries of e-bike riders over the past decade, with injury rates of about 0.25 injuries per 100,000 population in 2017 (Wen, Bukur et al. 2019). The crash rate increased sharply since 2012 (from 0.05 injuries per 100,000) corresponding to a large increase in e-bike ownership over the same time. About 40% of those injuries were soft-tissue injuries, 20% fractures, 17% internal injuries and 0.5% concussions or traumatic brain injury. Of those injured, 2.8% were admitted to the hospital. This study did not distinguish between classes of e-bikes. Exposure per-capita is less important than exposure per e-bike, or exposure per e-bike mile traveled. In 2017, there were an estimated 700,000 e-bikes in active service (Jamerson and Benjamin 2016). **The resultant *approximate* annual injury rate is 1.4 injuries per 1,000 e-bikes.**

To put this study into context, a similar study of the Centers for Disease Control's WISQARS injury database identified the number of crashes by conventional bicycle and estimated crash rates (Buehler and Pucher 2017). In 2010, the fatality rate for bicyclist was 4.7 per 100 million kilometers cycled. Exploring the same WISQARS database, there were 405,095 conventional bicyclist injuries in 2016 (35,882 requiring hospital admission). In several studies, severe injuries for bicyclists (i.e., those requiring admission to a hospital) were between 8-12% of emergency department visits (compared to just 2.8% for e-bikes reported above). The number of emergency department visits for conventional bicycle injuries in the U.S. is 125 per 100,000 people. The annual sales of conventional bicycles is approximately 17 million (Statista 2019) and there are likely 30-50 million active bicycles on the road. **The *approximate* annual injury rate per active bicycle is about 10 injuries per year per 1,000 conventional bicycles.**

There are many complicating factors in comparing these two categories of bicycles. E-bikes are most often used for urban utilitarian riding (though gravel and mountain e-bikes are a growing segment), whereas conventional bicycle sales are driven by mountain bike sales in recent years. Baseline safety exposure data is difficult to gather in comparable ways. E-bike riders tend to use e-bikes more intensely, with more frequent and longer trips than bicyclists (Macarthur, Harpool et al. 2018). Thus, until consistent reporting in ICD-10 codes, coupled with reliable exposure data is available, it is difficult to have definitive answers on e-bike injury risk in the U.S.

European Studies

European studies have better reporting methods in addition to higher e-bike ownership rates. The first study to explore e-bike safety in hospitalization records, compared to a panel of bicyclist injuries, was conducted in the Netherlands (Schepers, Fishman et al. 2014). This study investigated 294 e-bike injuries (primarily low-speed pedelecs) and found that e-bike users were more likely to be involved in a crash requiring medical treatment. The injury severity levels of e-bike riders were found to be the same as conventional bicycle injury severity. E-bike riders did have fewer car-related crashes. A main cause e-bike injury injuries was due to higher incidence of "dismounting" crashes, particularly among the elderly losing their balance or otherwise injuring themselves when getting off of the e-bike. That team replicated their study in 2018, controlling for confounding variables such as age and amount of riding (exposure) (Schepers, Wolt et al. 2018). Again, they found that e-bikes had higher crash risks, and found that dismount injuries were higher, but when controlling for the number of kilometers ridden and age, ***all differences between e-bikes and conventional bicycles disappeared; e-bikes and conventional bicycles have the same crash risk.***

Switzerland has some of the most specific e-bike safety data and several studies have been published from there. A study of police crash data compared 504 e-bike crashes and 871 bicycle crashes (Weber, Scaramuzza et al. 2014). They found that severity rates between e-bikes and conventional bicycles were the same. Injured e-bike riders are more often older, are involved in single-vehicle crashes, and wear helmets. Papoutsi, Martinolli et al. (2014) explored hospitalization data of a single hospital in Switzerland. Similar to most bicycle crashes, e-bike riders predominately were involved in single-bicycle crashes, with reported fractures, but with some head injuries. Another more-recent Swiss study focused on head injuries (Baschera, Jäger et al. 2019) from trauma center admissions (i.e., more severe cases) and found that of e-bike and conventional bicyclists admitted to a trauma center, 60% sustained traumatic brain injury, most were mild concussions. E-bike riders had statistically higher severity scores. For both e-bike and conventional bicycle riders, helmet use resulted in lower head injury severity rates. The most recent study presented results of surveys of over 3,600 Swiss e-bike users and asked for self-reported crash details (Hertach, Uhr et al. 2018). They found that over 17% of e-bike riders have experienced a single-vehicle crash and almost all of them were related to roadway conditions, such as slippery conditions or getting caught in streetcar tracks. Behavioral issues like riding too fast for conditions or inability to balance also contributed to crashes. This study confirms that elderly riders have higher injury risk. An important factor of this study is that about 1/3 of respondents rode a Class 3 e-bike, while others rode a Class 1 e-bike. Thus, speeds could have an important role in type and severity of injuries. This study found that there were ***no differences in crash risk between Class 1 and Class 3 e-bikes, but that the self-reported injury severity was higher for Class 3 e-bikes.***

E-bikes have become very popular in Israel and one group of researchers has investigated e-bike injuries using hospitalization records. In their first study (Siman-Tov, Radomislensky et al. 2017) focused on trauma center data and documented 795 crashes over a two year period (constituting 2.9% of total crashes). They found that, as expected, the e-bike injury burden rose as e-bikes became more popular. E-bike and conventional bicycle injury rates were the same when in car-involved collisions. They also were able to document pedestrian and e-bike crashes, ultimately recommending better e-bike regulation and better dedicated bicycle infrastructure. In a follow-up study, they explicitly compared injury rates and types between e-bikes and conventional bicycles (Siman-Tov, Radomislensky et al. 2018). They found that the rate of e-bike hospitalizations was about half that of conventional bikes (4.3 injuries per 1000 bicycles compared to 2.2 injuries per 1000 e-bikes). In this study, they found that despite lower overall injury rates, e-bike riders had slightly higher head injury risk, lower extremity risk, and severe injuries requiring hospitalization. Unlike other studies, this crash risk did not highlight higher injury burden to elderly riders.

Naturalistic Studies of E-bike Rider Behavior

Short of high-quality crash or hospitalization data comparisons, several researchers have investigated safety-related behavior of e-bike riders through naturalistic studies. Naturalistic studies usually rely on a series of sensors that record the behavior of the cyclists while they travel through the transportation network during “natural” use. The sensors measure many safety proxies that can be used to compare between modes.

The most basic naturalistic data is Global Position System (GPS)-based probe data of e-bike use. From this dataset, researchers can extract types of infrastructure used and speed on that infrastructure. One of the first studies in the U.S. tracked Class 1 e-bike and conventional bike riders in the context of a mixed bikeshare system in Tennessee (Langford, Chen et al. 2015). The researchers focused on speed, wrong-way riding, stop sign compliance, and traffic signal compliance using GPS data from each bike. They found that compared to conventional bicycle riders, e-bike riders ride slightly faster (3 km/hr) in mixed traffic and ride slower (1.5 km/hr) on shared use pathways (greenways). A follow-up study on a fixed course found that e-bike riders rode faster on average over a trip tour, but speeds were the same on flat and downhill road segments, but were higher on uphill segments – e-bike riders speed gains for the trip were achieved on uphill segments when conventional bicycle speeds drop (Langford, Cherry et al. 2017). For other safety surrogates (wrong way riding, stop sign and signal compliance) e-bike riders behaved in the same way as cyclists, with similar violation rates.

There have been two larger scale cohort-oriented naturalistic cycling efforts underway in Europe, where researchers have instrumented conventional bicycles and e-bikes with an array of sensors and cameras to observe individual behaviors of cyclists and surrounding vehicles. This approach provides opportunities to conduct careful evaluation of conflicts but requires substantial data processing effort.

In Sweden, Dozza and Werneke developed an instrumented bicycle (BikeSAFE) and e-bike (E-BikeSAFE) platform to assess rider performance in natural riding environments (Dozza and Werneke 2014). Dozza et al. loaned 12 instrumented e-bikes to users in and compared to a parallel study of conventional bicyclists for two weeks (Dozza, Bianchi Piccinini et al. 2016). Over that time, they found that e-bike riders experienced more safety critical events, particularly conflicts with cars. The severity of the safety critical event was lower than by bicycles according to their methods. They found that e-bike riders traveled 4 km/hr faster than conventional bicycle riders on average. This study suggest that drivers and pedestrians may mis-interpret rider speed based on rider posture, i.e., riders are going faster than they seem given their pedaling intensity and posture, even if they are not going faster than a conventional bicyclist. Drawing from the same naturalistic study database, the research team found that e-bike riders ride faster, and brake harder than conventional bicyclists (Huertas-Leyva, Dozza et al. 2018). E-bike riders experience more unexpected hard braking events potentially because faster riding diminished reaction time in complex mixed-use riding environments.

In Germany, a research group developed a similar naturalistic e-bike rider study (Petzoldt, Schleinitz et al. 2017). They conducted a camera-based naturalistic study of 80 bicycle and Class 1 e-bike riders in German for four weeks. The study also included 10 Class 3 e-bike riders. They found that the overall rate of conflicts was the same between e-bikes and conventional bicycle riders, but that e-bike riders had more conflicts at intersections. They suspect that other road users (car drivers) will need time to adapt to this new mode that travels faster than expected. A follow-up study focused solely on conflicts and "time to arrival" of crossing traffic and found that higher speeds coupled with lower pedaling frequency of e-bike riders resulted in inaccurate estimates of arrival time (i.e., riders arrived faster than drivers estimated). This potentially confirms Dozza's finding on conspicuity and driver expectation challenges between drivers and e-bike riders. It is unclear how driver behavior will evolve to expect higher-speed e-bikes once they become more ubiquitous (Petzoldt, Schleinitz et al. 2017). The same German naturalistic study compared speed between bicyclists and Class 1 & Class 3 e-bikes (Schleinitz, Petzoldt et al. 2017) and found that, compared to conventional bicyclists, Class 1 e-bike riders travel 2 km/hr faster and Class 3 e-bike riders travel 9 km/hr faster (Schleinitz, Petzoldt et al. 2017). Re-analyzing the same dataset (Schleinitz, Petzoldt et al. 2019) they found that red-light running was nearly identical for conventional bicycle and Class 1 & Class 3 e-bikes, confirming findings from (Langford, Chen et al. 2015).

Speed

Average operating speed of different classes of e-bikes is an important contributor to safety performance. There has been sufficient naturalistic studies of low-speed Class 1 e-bikes (25 km/hr max assisted speed in Europe, 32 km/hr max speed in U.S.). These maximum assisted speeds are higher than the maximum running speeds of conventional bicycles. Just like conventional bicyclists, e-bike riders do not sustain speeds near the maximum. Most evidence points to average speeds a couple of km/hr higher than conventional bicyclists measured in the same study. There is some evidence that the speed differential is highest on uphill segments where e-bikes are able to sustain a more consistent higher running speed. There are fewer studies that have focused on speed of Class 3 e-bikes (Type L1e-B *speed pedelecs* in Europe) with a maximum assisted speed of 45 km/hr. Figure 3 illustrates all of the known speed studies for conventional bicycles and Class 1 and Class 3 e-bikes. In some studies, speed was incidentally reported in the context of other research objectives (e.g., physical activity studies). Across all studies, Class 1 e-bikes travel about 3.0 km/hr faster than conventional bicycles. There have only been five known studies of Class 3 e-bike speed. In those studies, average free flow pedaling speed ranged from 25 to 37 km/hr for Class 3 e-bikes, about double the average running speed for conventional bicycles. A recent study by SWOV differentiated Class 3 e-bike speeds on-road to be 32 km/hr and on shared bike paths of 29 km/hr (Stelling-Konczak, Vlakveld et al. 2017). Notably, first adopters of Class 3 e-bikes tend to use their e-bikes for long commutes, usually outside urban cores.

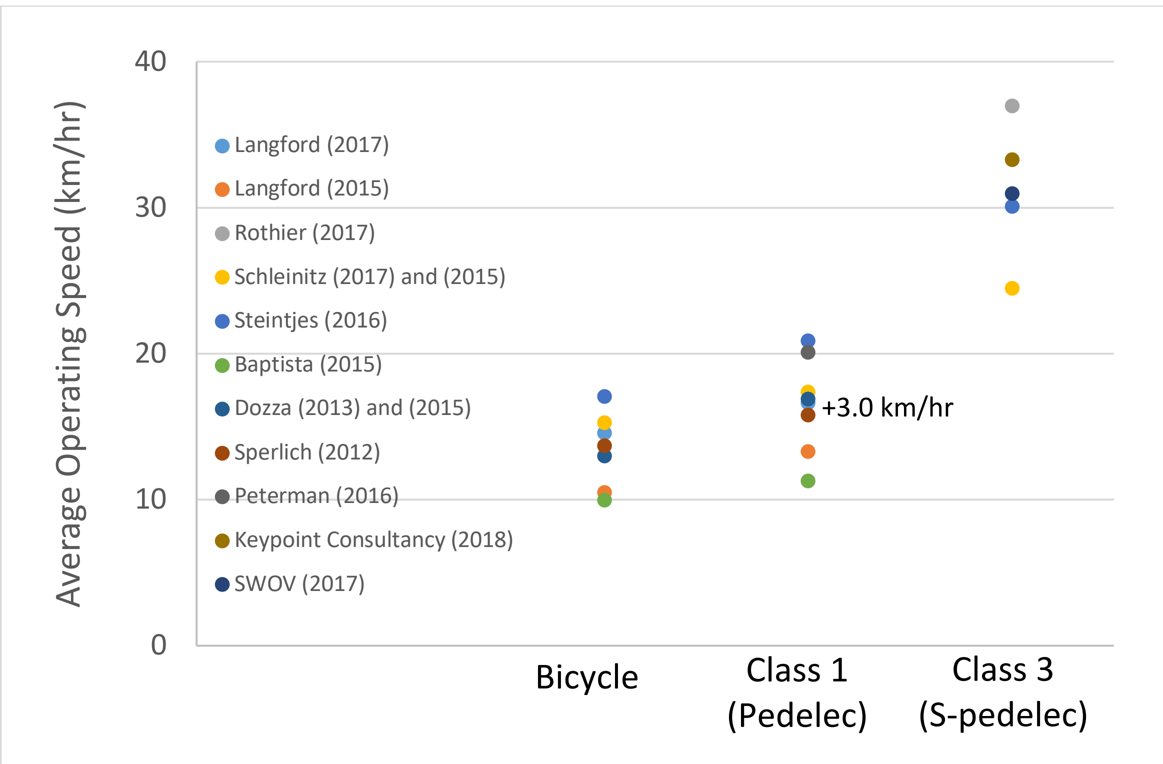

Figure 3
Summary of Average Speeds Observed in Empirical Studies

Note: Speed Studies included in Figure 3 (Sperlich, Zinner et al. 2012, Dozza and Bianchi Piccinini 2014, Baptista, Pina et al. 2015, Langford, Chen et al. 2015, Dozza, Bianchi Piccinini et al. 2016, Peterman, Morris et al. 2016, Schleinitz, Petzoldt et al. 2016, Steintjes 2016, Langford, Cherry et al. 2017, Schleinitz, Petzoldt et al. 2017, Stelling-Konczak, Vlakveld et al. 2017, Keypoint Consultancy 2018)

4. Conclusion

The field of e-bike safety research is small but growing. As with bicycle research, there is a lack of crash data, especially in the U.S. Ultimately, researchers are trying to answer the question of risk and severity of crashes.

- Is there a safety difference between e-bikes and conventional bicycles?
- Are e-bikes crashes more severe?
- Do speed differentials between e-bikes and conventional bicycles cause less-safe conditions for the riders and other non-riders or road users?
- Do different classes of e-bikes have different safety performance?
- Are different user groups more vulnerable than others?

A few studies have scrutinized police crash or self-reported crash and hospitalization data. Older riders tend to have slightly higher injury rates, but mostly related to balance while dismounting the heavier bike. Despite some evidence of higher hospitalization and injury rates, the average injury severity is about the same as cyclists' injury (Schepers, Fishman et al. 2014, Weber, Scaramuzza et al. 2014, Haustein and Møller 2016).

Finding 1: In Europe, controlling for the amount of riding and demographic variables, the differences between e-bike and conventional bicycle injury risk diminishes, considering both crash rate and crash severity. Class 3 e-bikes have the same crash risk as Class 1 e-bikes, but injury severity is slightly higher when they do crash. Some mixed findings point to slightly higher injury rates, despite lower risk of crashing in Israel.

Some of the main findings from existing research indicate that e-bike riders tend to behave similarly to bicyclists when considering speed and compliance with traffic control devices. Class 1 e-bike riders tend to ride 2-5 km/hr faster, on average. Riders tend to ride at higher speeds on uphill segments, but not flat or downhill segments. Because of higher speeds, e-bike riders tend to encounter more conflicts with cars, particularly at intersections. Potentially drivers have not adjusted their expectations of rider behavior. Higher speeds result in harder braking and more instances when cars pull in front of e-bike riders.

Finding 2: Class 1 e-bikes are marginally faster than conventional bicycles (3.0 km/hr). Their speed results in slightly higher conflict rates and safety-oriented maneuvers. Drivers require more education or experience riding near e-bike riders with a casual pedaling posture, but still traveling faster than a casual speed.

Finding 3: Class 3 e-bikes travel substantially faster than conventional bicycles, about twice the speed on average. There is little specific evidence (in crash or injury databases) that Class 3 e-bikes are overrepresented in injury databases, likely because Class 3 e-bikes are not distinguished. To the extent that errors and conflicts are compounded by speed (as shown in naturalistic studies), Class 3 e-bikes could generate higher speed-related crash risk.

One of the key factors when determining net safety impacts is exploring the behavioral shifts related to e-bikes. Most e-bike riders in North America ride farther and more often than conventional bicycling counterparts. E-bike riders also tend to use the e-bike for more utilitarian trips and replace more car trips than conventional bicyclists (Langford, Cherry et al. 2013, Macarthur, Dill et al. 2014, Popovich, Gordon et al. 2014, Macarthur and Kobel 2016, Ling, Cherry et al. 2017).

The research on e-bike safety has not found definitive negative or positive safety impacts. E-bikes tend to be a little faster on average, but top speeds don't tend to be faster. Much of the speed advantage occurs on uphill sections. Reduced travel time is an appealing factor of e-bikes but speed increases exacerbates some conflicts and perhaps creates expectation problems with other road users. Some of the increases in injury burden have occurred among a particularly vulnerable user group, older riders. E-bikes are more likely to be involved in single-vehicle crashes (e.g., dismounting). As e-bikes become more ubiquitous in North America, injury burden will naturally increase, but likely accompanied by a decline in other vulnerable and non-vulnerable road user injuries. Regulations should be tailored to assure e-bike vehicle design, infrastructure design, and operations maintain safety of all road users while promoting innovation.

Improved data collection and injury surveillance systems would assist in better analysis in the U.S. case. Swiss, Dutch, and Israeli injury systems tend to have higher volumes of data, and more consistently coded police and hospital crash coding, which has enabled better understanding of safety systems. As more e-bikes enter the market, more reliable information can be gathered on relative injury risk and other variables (demographic, built environment, and bicycle type) can contribute to a more complete picture of e-bike safety.

References.

Baptista, P., A. Pina, G. Duarte, C. Rolim, G. Pereira, C. Silva and T. Farias (2015). "From on-road trial evaluation of electric and conventional bicycles to comparison with other urban transport modes: Case study in the city of Lisbon, Portugal." Energy Conversion and Management **92**: 10-18.

Baschera, D., D. Jäger, R. Preda, W. J. Z'Graggen, A. Raabe, A. K. Exadaktylos and R. M. Hasler (2019). "Comparison of the Incidence and Severity of Traumatic Brain Injury Caused by Electrical Bicycle and Bicycle Accidents—A Retrospective Cohort Study From a Swiss Level I Trauma Center." World Neurosurgery **126**: e1023-e1034.

Buehler, R. and J. Pucher (2017). "Trends in Walking and Cycling Safety: Recent Evidence From High-Income Countries, With a Focus on the United States and Germany." American Journal of Public Health **107**(2): 281-287.

Dozza, M. and G. F. Bianchi Piccinini (2014). Do cyclists on e-bikes behave differently than cyclists on traditional bicycles? Proceedings of the 3rd International Cycling Safety Conference, Nov 18-19, Göteborg, Sweden.

Dozza, M., G. F. Bianchi Piccinini and J. Werneke (2016). "Using naturalistic data to assess e-cyclist behavior." Transportation Research Part F: Traffic Psychology and Behaviour **41**: 217-226.

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

Haustein, S. and M. Møller (2016). "E-bike safety: Individual-level factors and incident characteristics." Journal of Transport & Health **3**(3): 386-394.

Hertach, P., A. Uhr, S. Niemann and M. Cavegn (2018). "Characteristics of single-vehicle crashes with e-bikes in Switzerland." Accident Analysis & Prevention **117**: 232-238.

Huertas-Leyva, P., M. Dozza and N. Baldanzini (2018). "Investigating cycling kinematics and braking maneuvers in the real world: e-bikes make cyclists move faster, brake harder, and experience new conflicts." Transportation Research Part F: Traffic Psychology and Behaviour **54**: 211-222.

Jamerson, F. E. and E. Benjamin (2016). Electric Bikes Worldwide Reports - Light Electric Vehicles / EV Technology with 2016 update.

Keypoint Consultancy (2018). Effectmeting Uitzonderingsmaatregel speed-pedelecs.

Langford, B., C. Cherry, T. Yoon, S. Worley and D. Smith (2013). "North America's First E-Bikeshare." Transportation Research Record: Journal of the Transportation Research Board **2387**: 120-128.

Langford, B. C., J. Chen and C. R. Cherry (2015). "Risky riding: Naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders." Accident Analysis & Prevention **82**: 220-226.

Langford, B. C., C. R. Cherry, D. R. Bassett, E. C. Fitzhugh and N. Dhakal (2017). "Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles." Journal of Transport & Health **6**: 463-473.

Ling, Z., C. Cherry, J. Macarthur and J. X. Weinert (2017). Differences between cycling experiences and perceptions between e-bike and bicycle users in the United States. Transportation Research Board Annual Meeting, Washington DC.

Macarthur, J., J. Dill and M. Person (2014). "E-Bikes in the North America: Results from an online survey." Transportation Research Record: Journal of the Transportation Research Board **2468**: 123-130.

Macarthur, J., M. Harpool, D. Scheppke and C. Cherry (2018). A North American Survey of Electric Bicycle Owners, National Institute of Transportation and Communities.

Macarthur, J. and N. Kobel (2014). Regulations of E-bikes in North America, National Institute for Transportation and Communities.

Macarthur, J. and N. Kobel (2016). "Evaluation of an Electric Bike Pilot at Three Employment Campuses in Portland, Oregon." Transportation Research Board Annual Meeting **Accepted**.

Papoutsi, S., L. Martinolli, C. T. Braun and A. K. Exadaktylos (2014). "E-Bike Injuries: Experience from an Urban Emergency Department; A Retrospective Study from Switzerland." Emergency Medicine International **2014**: 5.

People for Bikes (2015). "New E-bike Law Passes in California." 2018.

Peterman, J. E., K. L. Morris, R. Kram and W. C. Byrnes (2016). "Pedelecs as a physically active transportation mode." Eur J Appl Physiol.

Petzoldt, T., K. Schleinitz, S. Heilmann and T. Gehlert (2017). "Traffic conflicts and their contextual factors when riding conventional vs. electric bicycles." Transportation Research Part F: Traffic Psychology and Behaviour **46**: 477-490.

Petzoldt, T., K. Schleinitz, J. F. Krems and T. Gehlert (2017). "Drivers' gap acceptance in front of approaching bicycles – Effects of bicycle speed and bicycle type." Safety Science **92**: 283-289.

Popovich, N., E. Gordon, Z. Shao, Y. Xing, Y. Wang and S. Handy (2014). "Experiences of electric bicycle users in the Sacramento, California area." Travel Behaviour and Society **1**(2): 37-44.

Schepers, J. P., E. Fishman, P. den Hertog, K. K. Wolt and A. L. Schwab (2014). "The safety of electrically assisted bicycles compared to classic bicycles." Accident Analysis & Prevention **73**(0): 174-180.

Schepers, P., K. K. Wolt and E. Fishman (2018). The Safety of E-Bikes in The Netherlands. International Transport Forum. Paris. **Discussion Paper**.

Schleinitz, K., T. Petzoldt, L. Franke-Bartholdt, J. Krems and T. Gehlert (2017). "The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles." Safety Science **92**: 290-297.

Schleinitz, K., T. Petzoldt, J. F. Krems and T. Gehlert (2016). "The influence of speed, cyclists' age, pedaling frequency, and observer age on observers' time to arrival judgments of approaching bicycles and e-bikes." Accident Analysis & Prevention **92**: 113-121.

Schleinitz, K., T. Petzoldt, S. Kröling, T. Gehlert and S. Mach (2019). "(E-)Cyclists running the red light – The influence of bicycle type and infrastructure characteristics on red light violations." Accident Analysis & Prevention **122**: 99-107.

Siman-Tov, M., I. Radomislensky, G. Israel Trauma and K. Peleg (2017). "The casualties from electric bike and motorized scooter road accidents." Traffic Injury Prevention **18**(3): 318-323.

Siman-Tov, M., I. Radomislensky, K. Peleg, H. Bahouth, A. Becker, I. Jeroukhimov, I. Karawani, B. Kessel, Y. Klein, G. Lin, O. Merin, M. Bala, Y. Mnouskin, A. Rivkind, G. Shaked, G. Sivak, D. Soffer, M. Stein and M. Weiss (2018). "A look at electric bike casualties: Do they differ from the mechanical bicycle?" Journal of Transport & Health **11**: 176-182.

Sperlich, B., C. Zinner, K. Hébert-Losier, D.-P. Born and H.-C. Holmberg (2012). "Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling." European Journal of Applied Physiology **112**(12): 4015-4025.

Statista (2019). Bicycle industry in the U.S. .

Steintjes, S. B. (2016). "COMPARING AND ANALYSING THE BEHAVIOUR OF USERS OF CONVENTIONAL BICYCLES AND SPEED PEDELECS: NATURALISTIC CYCLING." 1-32.

Stelling-Konczak, A., W. P. Vlakveld, S. Wesseling, J. d. Groot-Mesken, M. Christoph, A. J. Algera and D. A. M. Twisk (2017). Speed-pedelecs op de rijbaan: observatieonderzoek, SWOV. **R-2017-13A**.

Weber, T., G. Scaramuzza and K. U. Schmitt (2014). "Evaluation of e-bike accidents in Switzerland." Accident Analysis & Prevention **73**: 47-52.

Wen, A. Y., M. Bukur, S. Wall, S. Frangos and C. DiMaggio (2019). Injuries Related to Electric-Powered Bikes and Scooters. Pediatric Academic Societies, Philadelphia PA.