Safety Science xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Special Issue Article: Cycling Safety

The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles

K. Schleinitz[a,*], T. Petzoldt[a], L. Franke-Bartholdt[a], J. Krems[a], T. Gehlert[b]

[a] Cognitive and Engineering Psychology, Technische Universität Chemnitz, 09107 Chemnitz, Germany
[b] Traffic Behaviour/Traffic Psychology, German Insurers Accident Research (UDV), Wilhelmstr. 43/43 G, 10117 Berlin, Germany

ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form 16 July 2015
Accepted 30 July 2015
Available online xxxx

Keywords:
e-bikes
Speed
Acceleration
Infrastructure types
Naturalistic Cycling Study

ABSTRACT

In recent years, the number of electric bicycles on European, American and especially Chinese roads has increased substantially. Today, 11% of all bicycles sold in Germany are e-bikes. Given their potential to reach higher maximum speeds, concerns have been raised about a possible increase in crash risk associated with e-bike use. However, as of now, it is unclear if and how often the potentially higher speed is actually reached in everyday cycling. As part of the German Naturalistic Cycling Study we measured and compared the speed of three bicycle types (conventional bicycles, pedelecs (pedalling supported up to 25 km/h), S-pedelecs (pedalling supported up to 45 km/h)) under naturalistic conditions. Ninety participants, divided in three age groups, took part in our study. Participants used their own bikes or e-bikes. The bicycles were equipped with a data acquisition system, which included sensors to record speed and distance, as well as two cameras. Data was collected over a period of four weeks for each participant. Nearly 17,000 km of cycling were recorded in total. The statistical analysis revealed significant differences in mean speed between all three bicycle types. Pedelec riders were, on average, 2 km/h faster than cyclists. S-pedelec speed was even 9 km/h higher. A similar pattern was also found when analysing free flow conditions and uphill or downhill cycling separately. The highest speed was measured on carriageways and bicycle infrastructure, regardless of bicycle type. Participants aged over 65 years rode significantly slower than younger participants. Data on acceleration from standstill largely confirm the differences between bicycle types and age groups. The results show that electric bicycles indeed reach higher speeds than conventional bicycles regularly. Although it is unclear if this also leads to an increase in crash risk, it can be assumed that the consequences of a crash might be, on average, more severe.

1. Introduction

In recent years, the distribution of electric bicycles (e-bikes) has increased continuously. Especially in China, the number of e-bikes has risen substantially (Bundesministerium für Verkehr Innovation und Technologie, 2013). A similar trend can be observed in the US and in Europe (Rose, 2012). In Germany, about 1.6 million electric bicycles are currently on the road (Zweirad-Industrie-Verband, 2014), and it is expected, that this number will increase even further (Jellinek et al., 2013). As a result of this development, questions have been raised regarding a potentially increased crash risk for e-bikes. One central concern that has been voiced repeatedly is the fact that these e-bikes can reach a higher speed than conventional bicycles, which might lead to a variety of problems (Bai et al., 2013; Jellinek et al., 2013; Skorna et al., 2010). Scaramuzza and Clausen (2010) estimated an increase of severe injuries of about 150%, and an increase of even 350% for fatalities, if the overall cycling mean speed would increase by 6 km/h as a result of the growing distribution of e-bikes.

Data on the speed of conventional bicycles have been inconsistent. Two US studies found comparable mean speeds of 18 km/h (Dill and Gliebe, 2008) and 16 km/h (Thompson et al., 1997). Other investigations from Europe have reported mean speeds between 12 km/h and 14 km/h for conventional cyclists (Dozza and Werneke, 2014; Menghini et al., 2009). Up until now, only few studies have investigated the average speed of e-bikes. Results from China (Cherry and He, 2009; Lin et al., 2007) suggest that e-bikes are considerably faster than conventional bicycles. Mean speeds were found to be 7 km/h (Lin et al., 2007) and 5 km/h (Cherry and He, 2009) higher, respectively. For users of a US bike share programme higher travel speeds were found for e-bikes (13 km/h) in comparison to bicycles (11 km/h) on carriageways,

* Corresponding author.
E-mail addresses: katja.schleinitz@psychologie.tu-chemnitz.de (K. Schleinitz), tibor.petzoldt@psychologie.tu-chemnitz.de (T. Petzoldt), luise.bartholdt@psychologie.tu-chemnitz.de (L. Franke-Bartholdt), josef.krems@psychologie.tu-chemnitz.de (J. Krems), t.gehlert@gdv.de (T. Gehlert).

http://dx.doi.org/10.1016/j.ssci.2015.07.027
0925-7535/

Please cite this article in press as: Schleinitz, K., et al. The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles. Safety Sci. (2015), http://dx.doi.org/10.1016/j.ssci.2015.07.027

whereas e-bike speed was lower on shared use facilities (Langford et al., 2015). For Europe, a Swiss study (Paefgen and Michahelles, 2010) reported an e-bike mean speed of about 19 km/h, however lacked comparable data for conventional bicycles. An observational study in Germany recorded a mean speed of nearly 17 km/h for e-bikes (Alrutz, 2012, 2013), which was two to three km/h higher than for conventional bicycles.

Unfortunately, the term e-bike has been applied to a very broad range of vehicles, with a high variance in the support they provide, and subsequently with profound differences in the potential maximum speed. In China, some scooters with only rudimentary pedals are considered e-bikes (Cherry and Cervero, 2007). Such vehicles would hardly be called e-bikes by European standards. But also in Europe, different categories of electric bicycles exist. In Germany, we distinguish between so called pedelecs, which support pedalling up to 25 km/h (250 W), and S-pedelecs, which support up to 45 km/h (500 W) (Zweirad-Industrie-Verband, 2012). Similar categorisations (often with consequences for licensing, insurance etc.) exist in most European countries (Jellinek et al., 2013). It is obvious that comparisons of operating speed between different studies from different countries all over the world, with different traffic environments, different cyclist populations, and different bicycle categories are problematic.

Adding to this problem is the fact that the cited studies use a variety of different methodologies, each with their individual shortcomings and restrictions. Many investigations covered only a limited range of infrastructure types, as they either used a stationary (Jellinek et al., 2013; Lin et al., 2007; Thompson et al., 1997) or "floating vehicle" (Cherry and He, 2009) approach. This might result in a considerable bias in the data (limited infrastructure and traffic environment, bias in the observed cyclist populations, trip purposes etc.), and can limit the generalisability of the findings. Such observations also hamper the assessment of the influence of a variety of variables, as age, gender and even bicycle type have to be judged by an observer and cannot be directly collected (Jellinek et al., 2013; Lin et al., 2007). Other issues include limitations in subject samples or the lack of proper control groups (Paefgen and Michahelles, 2010).

The aim of this study was the investigation of speed (including acceleration) of electric bicycles in comparison to conventional bicycles. In order to avoid the described methodological issues, the naturalistic cycling methodology appeared to be most appropriate. In naturalistic observations, cameras and sensors are used to record the road users' usual behaviour to obtain data that is not contaminated by the influence of experimental manipulation. With motorised vehicles, *Naturalistic Driving Studies* (NDS) have been conducted for more than 20 years now (Dingus et al., 2006; Kessler et al., 2012; Lee et al., 2004). Only recently has the NDS approach been applied for the investigation of cyclist behaviour (so called *Naturalistic Cycling Studies*, NCS). Most NCS were interested in the identification of safety critical situations when riding a conventional bicycle (Dozza and Werneke, 2014; Johnson et al., 2010), while others focused on mobility behaviour or rider distraction (Gustafsson and Archer, 2013; Knowles et al., 2012). So far, no NCS has been conducted that addressed the speed differences between different bicycle types. Our study investigated the speed and acceleration of conventional bicycles, pedelecs and S-pedelecs without restrictions, taking into consideration aspects such as infrastructure, road gradient and riders' age.

2. Method

2.1. Participants

Participants were recruited through newspaper ads or flyers in cycling shops. The applicants filled in a recruitment questionnaire, which included questions on their socio-demographic status and technical data of their bicycle, with special focus on the bicycle type (conventional bicycle, pedelec, S-pedelec). Applicants were selected for participation based on criteria such as bicycle type, frequency of usage and age. As we were especially interested in e-bikes, we tried to recruit as many e-bike riders as possible. However, since S-pedelecs are still rather rare (Preißner et al., 2013; Zweirad-Industrie-Verband, 2013), there were relatively few applicants for this group. At the same time, we had a substantial number of candidates for the pedelec category. Those candidates were, on average, older riders, which is in line with the reported age structure of the overall pedelec rider population in Germany (Alrutz, 2013; Preißner et al., 2013). To ensure comparability of our different user groups, we selected users of conventional bicycles for participation matching the age of the pedelec riders. 90 cyclists took part, however data of five participants had to be excluded from analysis as the data sets were incomplete. 85 datasets (32 female, 53 male), divided in three age groups (see Table 1 for an overview), remained for analysis.[1] Gender was not equally distributed across the different bicycle types. Our S-pedelec riders were all male, whereas in the other two groups, distribution was more (although not fully) even (bicycle: 11 female, 17 male, pedelec: 21 female, 27 male). As participants were supposed to use their own bicycles for the study, we saw a wide range of different bicycle types. The majority of our participants' conventional bicycles were so called city bikes, with also a few mountain bikes. Only two pedelec riders owned a mountain bike style pedelec, the rest were all city bikes. All S-pedelec riders used trekking or city bikes. Nearly 60% of the e-bike riders reported to use a regular bicycle in addition to their e-bike. All participants received 100 EUR for their participation.

2.2. Data Acquisition System (DAS)

Trained technicians installed and uninstalled a Data Acquisition System (DAS) on the participants' own bicycles. A speed sensor was installed on the front wheel to record speed and distance data (data rate 2 Hz). Two cameras (Type ACME FlyCamOne eco V2), placed in a small box, were mounted on the handlebar. One camera captured the forward scenery and the other the face of the cyclist. The videos were recorded at 30 frames per second with a resolution of 720×480 pixels (VGA). All data was stored on two SD-memory cards, one for video (32 GB) and one for speed data (4 GB). Participants started and stopped recording with a flip switch.

2.3. Procedure

The study was conducted in and around Chemnitz (Germany) from July to November 2012. Exposure to different weather conditions did not differ between the three bicycle types, as we made sure that during the whole period of data acquisition, the same proportion of conventional bicycles, pedelecs and S-pedelecs was instrumented. For each participant, data was recorded over a period of four weeks. Weather conditions varied from hot and sunny in summer to cold and icy in October. An individual appointment for the installation of the DAS was arranged with each participant. In order to check their level of cycling ability, the technician conducted a short cycling skill test with the participants. None of the participants showed any specific deficits. During the course of the observation period, participants were instructed to use their bicycles as they would do normally. They were supposed to record

[1] Due to the use of stricter criteria for the inclusion of datasets, the subject sample differs slightly from the published research report (Schleinitz et al., 2014). Consequently, values in descriptive statistics differ as well. However, the overall findings based on inferential statistics are identical.