# Comparison of Rides on an Electric and a Conventional Bicycle in a Naturalistic Cycling Study

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## ABSTRACT

**Pedelecs are e-bikes which only assist the rider while pedalling. During the last years, their number has increased continuously. In 2015, their market share in bicycles was 12.5 % in Germany [1]. Whether this causes risks in mixed traffic with conventional bicycles or if existing cycling infrastructure is appropriate for the use with pedelecs, is part of current research.**

**To determine differences in the use of pedelecs and conventional bicycles in traffic, field tests were conducted in Berlin. A pedelec and a conventional bicycle with similar geometry and features were equipped with identical measuring systems, consisting of four cameras, two microphones and a GPS unit. Seven subjects rode each of the vehicles for a week, mostly for trips to and from the workplace in an urban area. Over 900 km worth of data were recorded.**

**The average speed for all riders was 19.5 km/h on the pedelec and 17.5 km/h on the conventional bicycle. An even bigger difference is found in the comfort speeds, the speed chosen by the rider on unobstructed infrastructure: On the pedelec, it was about 25.9 km/h, which corresponds to the built-in limitation for motor assistance. This is implemented for the pedelec to be qualified as a bicycle according to German law. On the conventional bicycle, the comfort speed was significantly lower, with 21.8 km/h.**

**In Berlin, use of most bicycle paths is not obligatory. Riders may decide to cycle on the road instead. However, no significant differences in infrastructure choice were observed between rides on the pedelec and conventional bicycle.**

**Keywords:** naturalistic cycling, fot, pedelec, e-bike.

## 1 INTRODUCTION

The number of electric bicycles on the road has increased in the last years. With the motor assistance, people are able to travel greater distances with the same exertion level than on conventional bicycles. The number of trips suitable for bike use increases. People with limited fitness may gain the ability to use a bike in the first place. Unexperienced cyclists are able to travel at higher speed. If the potential of e-bikes is fully used by the cyclists and if the habits differ from use of conventional bicycles is part of current research. In Gothenburg, Chalmers University of Technology conducted field tests with instrumented bicycles and e-bikes. A strong focus was set on critical situations [2]. In Germany, 90 probands had their e-bikes and bicycles equipped with data loggers for a study of the GDV (The German Insurers). The data of 4000 rides was analysed in regard of infrastructure use and critical situations [3]. The SWOV Institute for Road Safety Research, together with Delft University of Technology in the Netherlands, compared rides on e-bikes and bicycles on a given route. The focus was on safety of elderly people. During the rides, mental workload was determined [4].

In Germany, pedelecs are not classified as a motor vehicle if the motor has a continuous rated power of 250 Watts or less and only assists the rider while pedalling. Motor assistance has to cease at 25 km/h. Up to 6 km/h, the motor may work without pedalling. When these conditions are fulfilled, the same traffic rules apply as to bicycles. Bicycle infrastructure use is only mandatory when it is specifically signposted with one of three possible round signs with a white bicycle pictogram on blue ground (bicycle infrastructure; shared bicycle and pedestrian infrastructure; divided bicycle and pedestrian infrastructure). Helmet use is not compulsory. Sidewalks and bus lanes may only be used if signposted. For so-called S-Pedelecs (Schnelle Pedelecs – fast pedelecs), the motor assistance ceases at 45 km/h. These vehicles are regarded as mopeds and thus are not allowed to use bicycle infrastructure. Helmet use and insurance are mandatory for them.

In Berlin, an initiative for better and safer cycling infrastructure recently collected 89,729 verified signatures to enable initialisation of a cycling referendum. Only 20,000 signatures were necessary [5]. This shows that the existing cycling infrastructure and progress of enhancement is perceived as not sufficient by the citizens. The Berlin senate is now under pressure to improve the situation. If the referendum comes into action, it would result in a strict and straight forward law. Some of the requirements that would have to be fulfilled during the next eight years are instalment of 350 km of bicycle boulevards with a width of at least 5 m and right of way, at least 100 km of bicycle highways, and secure and comfortable bicycle infrastructure along all main roads. Other demands affect bicycle parking, convenient timing of traffic lights, better processes at traffic administration, and police units on bicycles in all districts.

For research on cyclists' behaviour, different sources of data are available, while many of them are not suitable for analysing their habits in detail. Police reports are mostly limited to accidents with injuries and fatalities, but do not contain information on everyday cycling. Some communities collect data on infrastructure use, in example with the aid of inductive loops built into the driving surface, counting passing bicycles. This data provides information about peak times, but no insight into individual cyclists' behaviour. A possibility to compensate these flaws comes with naturalistic cycling studies, where cyclists are observed during their routine participation in traffic. This can be done either by stationary methods, as cameras mounted on objects like traffic light posts, or in a mobile manner, with measuring equipment mounted on the proband's or a following vehicle. With these setups, it is possible to detect influences on the safety and comfort of cyclists, which would otherwise remain unrecognized. Obstacles, dangerous situations and near accidents may become detectable. This can help in establishing measures to improve the surroundings, which may lead to an increase in bicycle traffic, a goal aspired by many modern cities.

This small-scale study was conducted to disclose differences in the use of pedelecs and conventional bicycles. For good comparability, conditions for both vehicle types were kept similar. They were driven by the same probands on mostly the same route. Pedelec and bicycle were chosen to have a similar geometry and configuration. The same measuring equipment was used on both vehicles. In a previous study, 50 probands rode a fixed route of 3.5 km two times on the pedelec, whilst one time the motor was turned off to simulate a bicycle. Similar measuring equipment to this study was used [6].

## 2 METHODOLOGY

### 2.1 Hardware

A pedelec and a conventional bicycle were equipped with measuring systems. The Video VBOX by manufacturer Racelogic, a system originating in motorsports, was chosen. It consists of a logging unit, which stores data of four cameras, two microphones, and GPS data onto a memory card. The cameras were directed to the front, back, left and towards the rider. The system is powered by a battery pack and has to be turned on by the subject at start of the trip. The battery pack lasts for at least five hours. It was charged daily by the researcher.

Both vehicles have trekking bike geometry with a step-through frame, derailleur gears and hydraulic disc brakes. They are equipped with cyclocomputers. The pedelec's motor is located at the bottom bracket, the battery on the luggage carrier. According to German law, the motor has a continuous rated power of 250 Watts. The maximum power output is higher. The weight of the pedelec, including equipment, is 29 kg. The bicycle weights 19.5 kg.

The equipment was installed in a lockable case on the luggage carrier for protection against weather influences and opportunistic theft. Visible parts of the measuring system were mounted in a manner to minimize attraction of attention.

### 2.2 Subjects

Seven subjects were recruited from the institute's environment. Requirements were availability of a secure parking space for the vehicle and a suitable trip distance. Due to the employee demographics, all subjects were male and around 30 years of age. Their cycling habits ranged from occasional cyclist to everyday cyclist. None of them had used an e-bike on a regular basis before.

**Figure 1.** Bicycle and pedelec.


**Figure 2.** left: Measuring equipment on the pedelec, right: Data logger box.

### 2.3 Field Test

The subjects rode each of the vehicles for one week. The order of which of the vehicles was used first was alternated. Mostly trips from and to work were made, but some subjects also went for private trips. No special tasks were given, to keep the attention of the probands off of the testing conditions, so that they behave in a natural way. The subjects were encouraged to ride in their everyday manner.

The field test was conducted from September to October 2014, under mostly, but not exclusively, dry weather conditions.

### 2.4 Data Processing

Per trip, the measuring system creates a video file with the output of the cameras arranged in four sectors (see **Figure 3**), as well as a text file containing the data channels with a resolution of 10 Hz.


**Figure 3.** Screenshot of a video as created by the data logger.

The videos were viewed and annotated by a single researcher, using ELAN software. During this process, five channels were created with the following data: Mode of travel (cycling/walking/other), infrastructure type, critical situation (as perceived by the annotator), events from the incident protocol, and if the subject was riding with company. The software offers the possibility to watch the videos in up to twice the speed. This was useful for longer sequences with no intersections or other traffic participants.

Using MATLAB, the data files were merged with the annotation files. Parts of the trips with no valid GPS signal were interpolated or cut, if at the beginning or end. Non-cycling sections were removed, as well as sections where the subject was in company of another person.

## 3 RESULTS

Data of 926 km was suitable for analysis, 495 km on the pedelec and 431 km on the conventional bicycle. Total ride time was 51.5 hours, on 144 trips.

### 3.1 Use of Infrastructure

In Germany, use of cycling infrastructure is not mandatory, unless specifically signposted. Sidewalks may not be used by cyclists, with exceptions per sign. This is rarely the case in Berlin. Most bus lanes in Berlin are allowed for cyclists. Cycle paths and lanes may only be used on the right-hand side, with few specifically signposted exceptions. Additionally, Berlin has 17 bicycle boulevards.

Most of the trips took place in the city centre, with parts in suburban areas.

**Table 1.** Distribution of infrastructure use.

| Infrastructure type | Legal? | Pedelec [%] | Bicycle [%] |
|---|---|---|---|
| Cycle path | Y | 35.8 | 36.9 |
| Cycle lane (on-road) | Y | 11.5 | 13.5 |
| Road | Y/N | 33.0 | 30.9 |
| Bus lane | Y (if signposted) | 2.7 | 1.7 |
| Sidewalk | N | 7.5 | 8.3 |
| Shared bike path/sidewalk | Y | 4.1 | 4.3 |
| Bicycle boulevard | y | 1.3 | 0.9 |
| Other | | 4.1 | 3.6 |

For both vehicles, the shares of use of different infrastructure types were calculated. Only slight differences in infrastructure use can be seen between rides on the conventional bicycle and pedelec. The Wilcoxon rank sum test was conducted for each infrastructure type, testing the share of use of all riders on the conventional bicycle against pedelec rides. For no infra-structure type, a preference with one of the vehicles could be assumed on a 5 % level. It is supposed that infrastructure choice depends mostly on habits, which did not change during the rather short test period of one week per subject and vehicle.

Use of cycle paths was dominant in the data, closely followed by rides on the road. Cycle lanes were the third-most frequently used infrastructure type. The shares are mainly determined by the availability of the infrastructure type in the examined area. Cycling on sidewalks where it is not allowed had a share of 7.5 % on the pedelec and 8.3 % on the bicycle. Reasons for this be-haviour was, as apparent in the video data, lack of bicycle infrastructure, insufficient infra-structure width and quality, and convenience.

### 3.2 Riding Speed

A preferred speed was determined for each rider and vehicle. It is defined as the maximum in the speed distribution over distance. All of the subjects took full advantage of the motor assis-tance of the pedelec, which effectively ceases at around 26 km/h. Therefore the preferred speed is close to this value. On the conventional bicycle, only a slight difference to the pedelec rides of about 1 km/h was found for the two fastest riders. The slowest rider took the biggest advantage from the pedelec, with a difference of 7.4 km/h compared to his non-motorized rides.

**Table 2:** Preferred speed of the riders.

| Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Pedelec [km/h] | 26.3 | 25.3 | 25.8 | 25.2 | 26.8 | 25.5 | 26.2 |
| Bicycle [km/h] | 20.9 | 20.8 | 24.9 | 19.5 | **25.5** | **18.1** | 23.3 |

The average speed was calculated including and excluding stops. The values including stops are interesting for problems regarding the infrastructure. They may be used for comparison with other modes of transportation and overall travel time. The values excluding the stops are better suitable for comparison of the individual cyclists. They reflect how the two different vehicles were actually used, without random influences of traffic lights or other reasons for stopping. The differences in average speed between pedelec and conventional bicycle are more obvious when stops are disregarded, since stop frequencies and stop times can be assumed to be similar on both vehicles.

**Table 3:** Average speed of the riders.

| | Subject | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Including stops | Pedelec [km/h] | 18.0 | 19.2 | 20.2 | 18.5 | 21.5 | 18.1 | 20.7 |
| | Bicycle [km/h] | 17.1 | 16.8 | 19.5 | 15.5 | 19.9 | 14.7 | 18.4 |
| Excluding stops | Pedelec [km/h] | 23.5 | 23.5 | 24.0 | 21.9 | 25.6 | 22.6 | 24.4 |
| | Bicycle [km/h] | 21.3 | 20.3 | 23.1 | 18.6 | 23.7 | 18.3 | 21.5 |

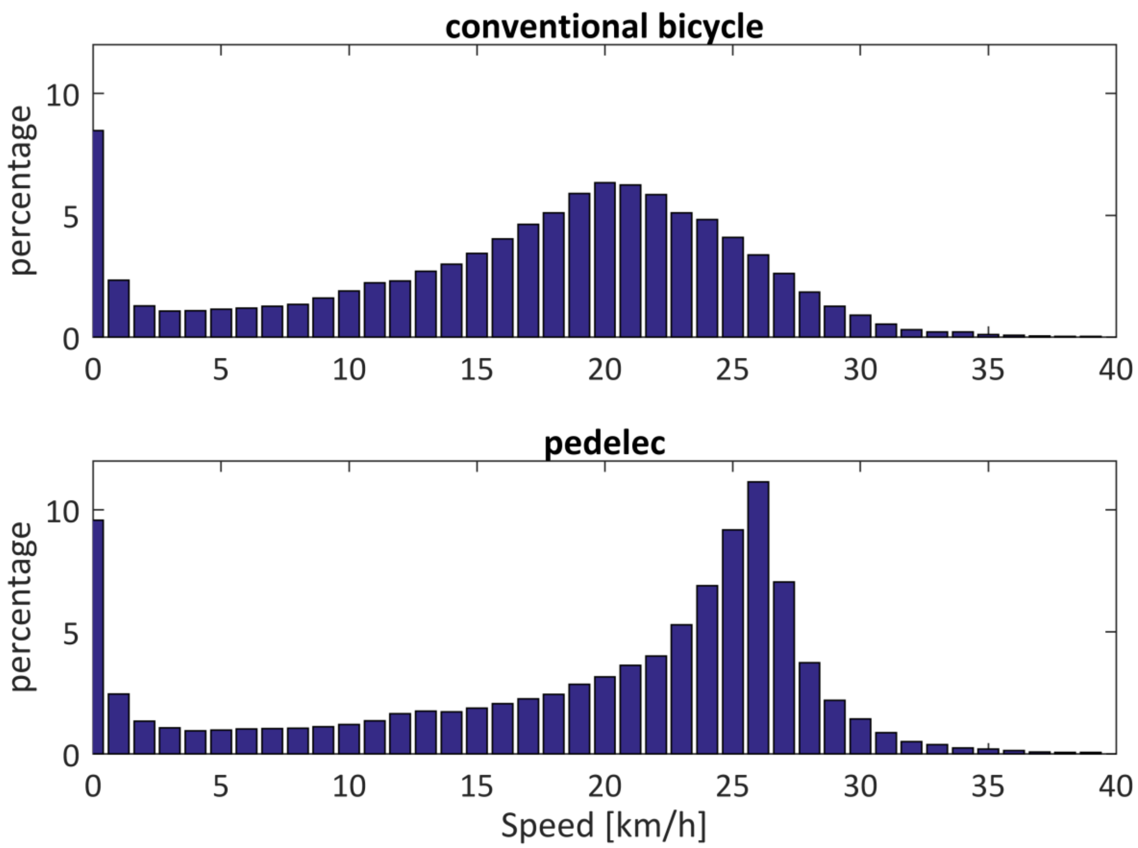


**Figure 4.** Speed distribution of all trips. Percentage of riding time.

A great difference in the characteristics of pedelecs and bicycles can be seen in the speed distribution (see **Figure 4**). Speed on the bicycle is much more diversified around a peak at 20 km/h. The pedelec has a thin peak at 26 km/h, where the utilized vehicle's motor support ceased. The driven speed on the bicycle seems to be limited by the physical capabilities of the rider. Influences such as opposing wind, inclines or retarding surfaces limit the rider, while the motor of the pedelec can compensate them. Other limiting influences however cannot be compensated, as lack of space for overtaking slower individuals or complex traffic situations.

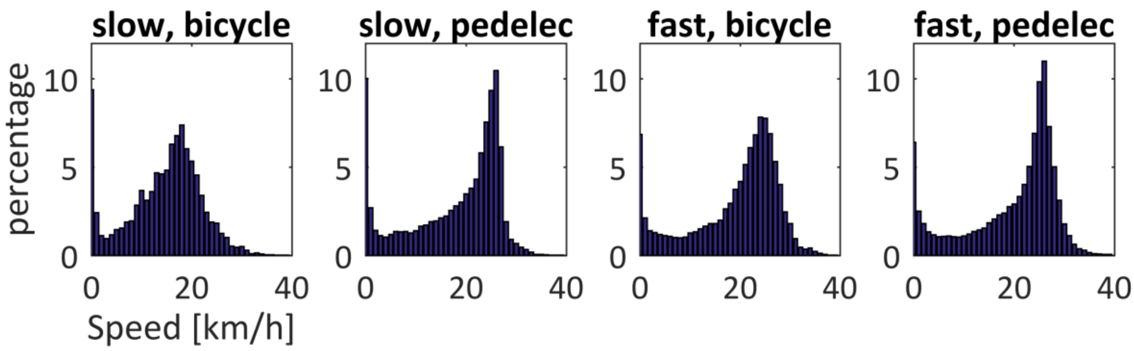


**Figure 5.** Speed distributions of the slowest and fastest rider.

In comparison of the slowest and fastest rider, it can be seen that for the fast rider the peaks are at almost the same position, whilst there is a difference of 7 km/h between them for the slow cyclist (see **Figure 5**).

## 4 DISCUSSION

### 4.1 Measuring Equipment

The chosen hardware was sufficient for the study. The four cameras provided an almost all-round view of the surroundings. When the output of one camera was unusable, the situation could still, with limitations, be evaluated via the remaining cameras. Since video and sensor data were recorded by the same device, no synchronisation problems occurred. These were reported to be huge issues in other studies. Additional sensors can be added via CAN bus. As an out-of-the-box solution, configuration efforts are minimized.

The video material was usable most of the time. In dark situations, when water drops were on the lenses or when glared, details in the image were difficult to recognize.

The speed channel provided by the logger proved to be unreliable. The Doppler-derived channel seems to be negatively influenced by multipath effects when objects are near. It was re-calculated from the position data.

The 10 Hz logging rate was sufficient for this study. If, in example, acceleration and deceleration are to be analysed, a higher rate is recommended. A separate speed sensor is advised to avoid insecurities from GPS data.

### 4.2 Subjects

For insurance reasons, only probands from the institutes could be recruited. This resulted in a same-aged, all-male group with similar background and is therefore not representative. The probands however differed in their cycling habits: Two of them were active, regular cyclists. One was inexperienced. The remaining four rode bikes occasionally or on a regular basis.

### 4.3 Video annotations

Video annotation proved to be time consuming, with approximately twice the run time of the video material. It is therefore not recommended for large scale studies.

If only details of the trips which can be identified in the sensor data are to be analysed, work effort can be reduced. However, emergency situations are hard to detect from sensor data only. Accidents can, for example, be avoided by braking or evading or in some situations by accelerating. Other critical situation may not trigger a reaction at all because they are only noticed when they are already over.

### 4.4 Comparison with other studies

In this study, the determined use of sidewalks was 7.5 % on the pedelec and 8.3 % on the conventional bicycle. The “Pedelec-Naturalistic Cycling Study” found a similar share of 7.4 % for pedelecs and 9.2 % for bicycles. The shares of road use are much lower, with 36 % in this study versus more than 50 %, while use of cycling lanes with 12 % was much higher than 3 % in the “Pedelec-Naturalistic Cycling Study” [3]. The main reason for these differences can be found in the different arrangements of infrastructure in Berlin and Chemnitz.

The average speed of all riders, including stops, was 19.5 km/h on the pedelec and 17.4 km/h on the conventional bicycle. The study of Dozza et al. found a much lower average speed of 17 km/h for e-bike users, with only 2 of their 12 probands reaching higher average speeds.

## 5 CONCLUSION

For fast cyclists, the use of a pedelec has a small influence on their driven speed. They do, however, profit from the acceleration capabilities. A huge difference is seen for slow and average cyclists. Instead of using a broad speed spectrum, they tend to take maximum advantage of the motor aid.

With more pedelecs on the road, the overall speed of bicycle traffic increases. Especially cyclists with physical limitations are riding faster than they would on a regular bicycle. This may lead to more conflicts. Especially inexperienced riders may be having trouble judging potentially dangerous situations. They may, in example, not notice right-turning vehicles crossing their path as potential dangers or have a worse estimation of the actions of other participants in traffic than experienced riders. With higher speed comes a longer thinking and braking distance.

Pedelecs bear the potential of increasing the number of cyclists on the road. They may be used by people who don’t have the physical capabilities to use a regular bicycle, people who wouldn’t normally go for longer trips on a bike, or people who don’t use bicycles for other reasons, as to avoid sweating when commuting.

Additionally, in many places political decisions are made to support people’s traffic mode change from car to bicycle. Reasons for this are, amongst others, concerns about environmental problems, as well as traffic jams or lack of parking space.

With these factors leading to an increase of bicycles in traffic, communities have to put strong effort into providing safe and sufficient bicycle infrastructure. Adequate widths for allowing safe overtaking manoeuvres should be provided. Routing of bicycle paths has to be clear, as well as visibility.

The measuring equipment used gave a good insight into the traffic situation surrounding the participants of the study and can be recommended for similar test setups.

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