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Investigating cycling kinematics and braking maneuvers in the real world: e-bikes make cyclists move faster, brake harder, and experience new conflicts

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A B S T R A C T

Pedelecs (e-bikes), which facilitate higher speeds with less effort in comparison to traditional bicycles (t-bikes), have grown considerably in popularity in recent years. Despite the large expansion of this new transportation mode, little is known about the behavior of e-cyclists, or whether cycling an e-bike increases crash risk and the likelihood of conflicts with other road users, compared to cycling on t-bikes. In order to support the design of safety measures and to maximize the benefits of e-bike use, it is critical to investigate the real-world behavior of riders as a result of switching from t-bikes to e-bikes.

Naturalistic studies provide an unequaled method for investigating rider cycling behavior and bicycle kinematics in the real world in which the cyclist regularly experiences traffic conflicts and may need to perform avoidance maneuvers, such as hard braking, to avoid crashing. In this paper we investigate cycling kinematics and braking events from naturalistic data to determine the extent to which cyclist behavior changes as a result of transferring from t-bikes to e-bikes, and whether such change influences cycling safety.

Data from the BikeSAFE and E-bikeSAFE naturalistic studies were used in this investigation to evaluate possible changes in the behavior of six cyclists riding t-bikes in the first study and e-bikes in the second one. Individual cyclists' kinematics were compared between bicycle types. In addition, a total of 5092 braking events were automatically extracted after identification of dynamic triggers. The 286 harshest braking events (136 cases for t-bike and 150 for e-bike) were then validated and coded via video inspection.

Results revealed that each of the cyclists rode faster on the e-bike than on the t-bike, increasing his/her average speed by 2.9–5.0 km/h. Riding an e-bike also increased the probability to unexpectedly have to brake hard (odds ratio = 1.72). In addition, the risk of confronting abrupt braking and sharp deceleration were higher when riding an e-bike than when riding a t-bike.

Our findings provide evidence that cyclists' behavior and the way cyclists interact with other road users change when cyclists switch from t-bikes to e-bikes. Because of the higher velocity, when on e-bikes, cyclists appear to have harder time predicting movements within the traffic environment and, as a result, they need to brake abruptly more often to avoid collisions, compared with cycling on t-bikes. This study provides new insights into the potential impact on safety that a cycling society moving to e-bikes may have, indicating that e-cycling requires more reactive maneuvers than does cycling traditional bicycles and

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suggesting that any distractive activity may be more critical when riding e-bikes compared to traditional bikes.

1. Introduction

Pedelecs (e-bikes) are electric power-assisted bicycles that have become very popular in the past few years around the world, including China, Europe, Japan and the US (Fishman & Cherry, 2016). Many cities support the use of e-bikes as a means to reduce congestion and pollution (Ji, Cherry, Bechle, Wu, & Marshall, 2012) and increase mobility (Dill & Rose, 2012; Fyhri & Fearnley, 2015), especially for older people and people with limited access to urban public transport (Weinert, Ma, Yang, & Cherry, 2008). Cycling on e-bike requires less effort than cycling on a traditional bicycle (t-bike), enabling greater traveling distance and reducing the effects of such deterrents as wind or challenging terrain.

In most countries, national regulations classify e-bikes as bicycles, so there are fewer restrictions associated with riding e-bikes compared to other motorized vehicles such as minimum age or mandatory licensing (Cherry, Yang, Jones, & He, 2016). Such regulations are generally based on maximum power of the motor (e.g., 250 W in Europe and Japan) and maximum speed under power assistance (e.g., 25 km/h in Europe, 32 km/h in USA and Canada, 20 km/h China (Rose, 2012)). However, there is little international consensus about which features of the e-bike should guide regulation of e-bike use or how these features relate to safety.

Despite the large expansion of this new transportation mode, it is not yet known whether e-bikes change cycling behavior and whether cycling with an e-bike may increase crash risk and/or induce conflicts with other road users. Previous studies on e-bike safety have focused primarily on the impact of e-bike use on the transportation system (Cherry et al., 2016; Lee, Molin, Maat, & Sierzchula, 2015), differences in risk-taking behavior (Bai, Liu, Chen, Zhang, & Wang, 2013) or the risk of crashes requiring treatment at an emergency department (Schepers, Fishman, Den Hertog, Wolt, & Schwab, 2014). A few studies have investigated cycling behavior analyzing cycling speed. These include survey data (Weinert et al., 2008), controlled field trials (Vlakveld et al., 2015), or GPS and video surveillance measures along specific commuting routes (Cherry & He, 2009; Lin, He, Tan, & He, 2008). However, the methods used in these studies cannot provide an accurate picture of real-world cycling behavior: data from self-report surveys is subjective and may be questionable (self-report data can be biased by factors such as social desirability), and studies limited to specific field trials or routes have limitations for generalizability.

Naturalistic studies provide an unequaled method for investigating cycling behavior in the real world, where cyclists regularly experience traffic conflicts and may need to perform avoidance maneuvers, like hard braking, to avoid crashing. Using naturalistic data the cyclist's real-world behavior can be investigated by assessing cycling kinematics (e.g., operating speeds of cyclists and speed distribution), near misses and conflicts. Unfortunately, naturalistic data have certain limitations which may bias results geographically and demographically.

To date, only a few naturalistic cycling studies have compared cycling behavior on e-bikes versus t-bikes (Dozza, Bianchi Piccinini, & Werneke, 2016; Langford, Chen, & Cherry, 2015; Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2017). Langford et al. (2015) used a US university campus bike-sharing fleet to investigate they found e-bikes faster than t-bikes on streets and t-bikes riding speed behavior. Their results suggested that e-cyclists and traditional cyclist have a very similar riding behavior, although faster on shared-use paths. The study by Schleinitz et al. (2017) in Germany showed cyclists circulate faster on pedelecs (e-bikes) than on traditional bicycles. However, the results were inconclusive about effect of e-bikes on operating speed given that authors used a between subject design and the actual differences of the users populations of both type of bicycles might have biased the average speed values. The study of Dozza, Bianchi Piccinini, et al. (2016) in Sweden compared the ways e-cyclists and traditional cyclists interacted with other road users during critical events, suggesting that e-bike users travel faster and interact differently than traditional cyclists. In conclusion, the characteristics of cycling behavior have not been dealt with in depth and there is still some controversy with regard to whether riders behave differently when cycling on e-bikes compared to cycling on t-bikes and whether this difference has implications to safety.

In this study, we compare cycling behavior on e-bikes and t-bikes by analyzing cycling kinematics and braking events at individual level to determine (1) the extent to which cycling behavior changes in switching from t-bikes to e-bikes, and (2) whether such changes influence cycling safety. We analyzed data from the same cyclists using both e-bikes and t-bikes, collected in two different naturalistic cycling studies. Since speed has been shown to be associated with road safety (Elvik, Christensen, & Amundsen, 2004; Milliken et al., 1998), we analyzed speed profiles to characterize individual and overall cycling behavior on these two types of bicycles. Further, as braking is one of the main avoidance maneuvers when cycling (Maier, Pfeiffer, Wehner, & Wrede, 2015), this study investigated braking events as to determine whether e-cyclist brake differently or for different reasons than traditional bikers. By understanding speed profile and braking behavior our aim is to generate estimates of risk for comparing the two bicycle types.