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The influence of speed, cyclists' age, pedaling frequency, and observer age on observers' time to arrival judgments of approaching bicycles and e-bikes

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ABSTRACT

Given their potential to reach higher speed levels than conventional bicycles, the growing market share of e-bikes has been the reason for increased concerns regarding road safety. Previous studies have shown a clear relationship between object approach speed and an observers' judgment of when the object would reach a predefined position (i.e., time to arrival, TTA), with higher speed resulting in longer TTA estimates. Since TTA estimates have been linked to road users' decisions of whether or not to cross or turn in front of approaching vehicles, the higher potential speeds of e-bikes might result in an increased risk for traffic conflicts. The goal of the two experiments presented in this paper was to examine the influence of speed and a variety of other factors on TTA estimation for conventional bicycles and for e-bikes. In both experiments, participants from two age groups (20–45 years old and 65 years or older) watched video sequences of bicycles approaching at different speeds (15–25 km/h) and were asked to judge the TTA at the moment the video was stopped. The results of both experiments showed that an increase in bicycle approach speed resulted in longer TTA estimates (measured as the proportion of estimated TTA relative to actual TTA) for both bicycle types ($\eta_p{}^2{}_{Exp.1}$ = .489, $\eta_p{}^2{}_{Exp.2}$ = .705). Compared to younger observers, older observers provided shorter estimates throughout (Exp. I: M_{Diff} = 0.35, *CI* [0.197, 0.509], $\eta_p{}^2$ = .332, Exp. II: M_{Diff} = 0.50, *CI* [.317, 0.682], $\eta_p{}^2$ = .420). In Experiment I, TTA estimates for the conventional bicycle were significantly shorter than for the e-bike (M_{Diff} = 0.03, *CI* [.007, 0.044], $\eta_p{}^2$ = .154), as were the estimates for the elder cyclist compared to the younger one (M_{Diff} = 0.05, *CI* [.025, 0.066], $\eta_p{}^2$ = .323). We hypothesized that the cause for this effect might lie in the seemingly reduced pedaling effort for the e-bike as a result of the motor assistance it provides. Experiment II was able to show that a high pedaling frequency indeed resulted in shorter TTA estimates compared to a low one (M_{Diff} = 0.07, *CI* [0.044, 0.092], $\eta_p{}^2$ = .438). Our findings suggest that both the e-bikes' potential to reach higher speeds and the fact that they reduce the perceived cycling effort increase the risk of TTA misjudgments by other road users.

1. Introduction

In recent years, electric bicycles (e-bikes) have become increasingly popular (Rose, 2012). In Germany, already 1.6 million e-bikes are on the road (Zweirad-Industrie-Verband, 2014) and sales figures are expected to grow even more (Jellinek et al., 2013). Reasons for that popularity are that e-bikes offer a reduction in cycling effort, the possibility to compensate for physical impairments, and the potential to reach farther destinations more easily (Jellinek et al., 2013; Kuratorium für Verkehrssicherheit, 2011; Schleinitz et al., 2014). While these are desirable outcomes, not all potential consequences of the increased popularity are positive. In particular, safety concerns have been raised because the design of e-bikes is hardly distinguishable from that of conventional bicycles. However, in comparison, e-bikes reach higher mean and maximum speeds (Schleinitz et al., in press) and it has been argued that this could result in other road users misjudging the speed of an approaching e-bike (bfu-Beratungsstelle für Unfallverhütung, 2014; Skorna et al., 2010 Skorna et al., 2010). An e-bike user described it this way: "I had to be really conscientious of other drivers because they weren't expecting me to approach as quickly as I was. And so, in the

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beginning, I feel like cars were kind of cutting me off because they thought they had plenty of time.“ (Popovich et al., 2014, p. 42).

Unfortunately, actual crash statistics to support the assumption that e-bike riders are at an increased risk to be involved in a crash are not readily available. Data from China (Feng et al., 2010) appear to provide some evidence, with rates of casualties and injuries due to crashes involving an e-bike having increased over a period of five years, even after adjusting for growth of the e-bike population. However, an application of these findings to Western countries is limited since most of the two-wheelers that are categorized as e-bikes in China would be characterized as mopeds in Europe or the in the US. First data from Switzerland show a rise in the absolute number of crashes that involved e-bikes which resulted in severe injuries and causalities, however those numbers do not control for the fact that sales figures of e-bikes also increased (bfu-Beratungsstelle für Unfallverhütung, 2014). Findings from a naturalistic cycling study, which observed riders of conventional bicycles and riders of e-bikes for a period of four weeks found that, while overall risk was comparable, e-bike riders were at higher risk of being involved in a safety critical event in the direct vicinity of an intersection. It also appeared that motorists failed more often to yield to an e-bike than to a conventional bicycle (Petzoldt et al., 2015; Schleinitz et al., 2014). Data show that in collisions with e-bikes, the second party involved was found to be at fault in 70% of all cases, compared to 61% for conventional bicycles. According to the authors, this suggests that others underestimate the speed of the e-bike rider (Scaramuzza et al., 2015). This might be somewhat surprising, as drivers have to estimate speed, or, more precisely, time to collision (TTC) or time to arrival (TTA), “the time remaining before something reaches a person or particular place” (Tresilian, 1995, p. 231), on a regular basis. However, it is well established that, while in general the human ability to estimate TTA is sufficiently accurate, it is also prone to a variety of biases and errors.

Several experiments have shown an effect of speed on TTA estimation (e.g. Manser, 1999; Petzoldt, 2014; Recarte et al., 2005). Results from all of these studies indicate that higher speeds go with longer TTA estimates (which in turn should result in riskier driver decisions). Unfortunately, the speed levels that were studied ranged from 30 km/h to 120 km/h, i.e., they are hardly relevant for bicycles. However, the clear trends observed in these studies allow for the assumption that also at cycling speed levels, higher speeds (as they would be reached by e-bikes) would be accompanied by longer TTA estimates.

Another aspect that is linked to the specific features of e-bikes is the fact that they are, at least at the moment, attractive to a very specific user group. In Germany, for example, e-bike users are, on average, ten years older than conventional cyclists (Preißner et al., 2013). From other contexts, it is known that strong stereotypes exist in regards to the behavior of older road users. In a study by Joanisse et al. (2012), participants watched video clips with car drivers performing different driving behaviors and afterwards were asked to indicate how representative they thought the observed behavior was for a typical older driver. Not surprisingly, it was found that driving slowly was considered representative for older driver behavior. Similar findings were reported by Davies and Patel (2005). Since cycling and especially cycling speed are dependent on physical fitness, it is reasonable to assume that such stereotypes play also a role in the perception of bicyclists. How far this translates into differences in perceived approach speed is a question that, as of now, has not been answered.

However, not only the observer's perceptions of the rider and the riders' speed might have an impact on TTA judgments of approaching bicyclists. The age of the observer has been repeatedly found to have an influence on judgments of time gaps as well. In a study by Schiff et al. (1992), older participants showed a significantly poorer accuracy in TTA estimations than younger participants. Their estimates were consistently shorter than those made by younger observers, i.e., older participants perceived vehicles as arriving much earlier. Comparable results were also be found by Hancock and Manser (1997). Again, however, it is unclear if the same effects occur with considerably lower cycling speeds.

Table 1
Overview of all factors and factor levels.

Observer age group	Bicycle type	Cyclist's age	Speed	TTA
20–45 years	conventional bicycle	young	15 km/h	4 s
≥65 years	e-bike	old	20 km/h	6 s
			25 km/h	8 s

Therefore, the main interest of our experiments was to evaluate whether and to what extent variations in speed would result in corresponding variations in TTA estimates. For that purpose, two experiments were conducted to investigate the effects of speed and bicycle type (i.e., bicycle versus e-bike) on an individual's TTA estimation. In addition, in Experiment I we examined the influence of the cyclist's age. In Experiment II, we varied pedaling frequency, a manipulation that was suggested by the results of the first experiment. Finally, in both experiments we investigated whether the age of the observer had an influence on TTA estimations.

2. Experiment I

The purpose of Experiment I was to investigate the influence of approach speed, cyclist's age, and bicycle type on the TTA estimations of older and younger observers. Based on prior studies, we hypothesized that older observers would provide shorter TTA estimates than younger observers would. To extend the results of studies investigating TTA estimates of approaching cars, we predicted that an increase in speed would also lead to longer TTA estimations for smaller vehicles like bicycles. Based on results about the effects of stereotypes regarding the age of car drivers, that slower driving is representative of older people (Joanisse et al., 2012), we expected that an older cyclist would be estimated to arrive later than a younger one. In addition, we varied the bicycle type, using both a conventional bicycle and an e-bike.

2.1. Method

2.1.1. Participants

We acquired a sample of 44 participants for two predefined age groups (22 persons per group). The younger participants (20–45 years old) were on average 33.3 years old (*SD* = 8.1), the older ones (65 years and older) were on average 71.3 years old (*SD* = 3.7). Twenty-one participants were male and twenty-three were female (20–45 years: 8 male, 14 female, ≥65 years: 13 male, 9 female). All participants were in possession of a valid driving license. All had normal or corrected to normal visual acuity. For their participation, they received monetary compensation.

2.1.2. Experimental design

To address our hypotheses, we designed a video-based laboratory experiment in which different bicycles approached a stationary observer. The experiment made use of a mixed design where the age group of the observer was treated as a between subjects factor (see Table 1). The approaching vehicles were a conventional trekking bicycle (Diamant Ubari black) and a comparable e-bike (Diamant Supreme, Fig. 1). Both types of bikes were ridden by either a typical older (65 years) or younger cyclist (28 years). They were riding at constant speeds of either 15, 20, or 25 km/h. Furthermore, we used three different TTAs in order to avoid that the participants adapt to a single TTA value. This resulted in a total of 36 combinations that were presented in random order to the