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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* [.197, .509], $\eta_p^2 = .332$, Exp. II: $M_{Diff} = 0.50$, *CI* [.317, .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, .044], $\eta_p^2 = .154$), as were the estimates for the elder cyclist compared to the younger one ($M_{Diff} = 0.05$, *CI* [.025, .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* [.044, .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.

Keywords: electric bicycles, time to collision, ageing, intersection

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). 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 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.

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.

2.2. Method

2.2.1. 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.

2.2.2. 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, Figure 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 participants. The estimated TTA was treated as the dependent variable.

Figure 1: Conventional bicycle (left) and e-bike (right) used in the experiment.

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

2.2.3. Material

We used real world video scenes of approaching bicycles (Figure 2) which were recorded on a straight taxiway of a small general aviation airport. All scenes were recorded from a driver's point of view, i.e. the height of the camera position is comparable to the eye level of a driver sitting in a car. Figure 3 shows the bird's eye view of the scenario. We pasted a white line on the street surface that marked the position of a potential collision between the oncoming cyclist and the observer when turning left. All combinations of bicycle type, cyclist's age, and speed were filmed. When riding the e-bike our cyclists received no instructions as to how much assistance from the motor they should use. Instead, they were asked to use the level of assistance they considered suitable for the intended speed level and to have a setting that was as natural as possible. In general, our cyclists were free to choose an appropriate gear to reach each speed level. The recorded material was then cut into clips of 4 s length, with the end of each video clip set according to the three TTA levels. The material was then presented to our participants using a projector (projection image 125 x 220 cm) in order to give the participants a more realistic view of the cyclists. Participants were seated at a desk at a distance of 250 cm from the screen. The visual angle of the oncoming bicycle, including the rider, ranged from 1.87° to 4.67° (based on the last frame of the video before the bicycle was occluded) independent of bicycle and cyclist's age (Table 2).

Table 2: Overview over all factors and factor levels.

Speed	TTA	Visual angle
15 km/h	4 s	4.67°
	6 s	3.42°
	8 s	2.80°
20 km/h	4 s	3.74°
	6 s	2.80°
	8 s	2.28°
25 km/h	4 s	3.22°
	6 s	2.39°
	8 s	1.87°

2.2.4. Procedure

First, participants received instructions on the experiment. We explained that their task was to watch one short video clip at a time and while observing the approaching cyclist, participants were asked to put themselves in the position of a car driver at an intersection, waiting to make a left turn. After the clip ended (4 s runtime), the screen was blank and participants were asked to indicate the moment when they thought the bicycle would reach the white line by pressing the spacebar. After having been explained the procedure, the participants completed two practice trials to become familiar with the task. Then, in the experimental phase, they were presented with one clip for each factor combination, which resulted in 36 trials. The complete session lasted 15 to 20 minutes.

Figure 2: Screenshot from one of the video sequences (i.e., the observer's perspective). The horizontal white line marked the position of a potential collision between the oncoming cyclist and the observer (when turning left). The dotted line represents the observer's hypothetical left-turn trajectory.

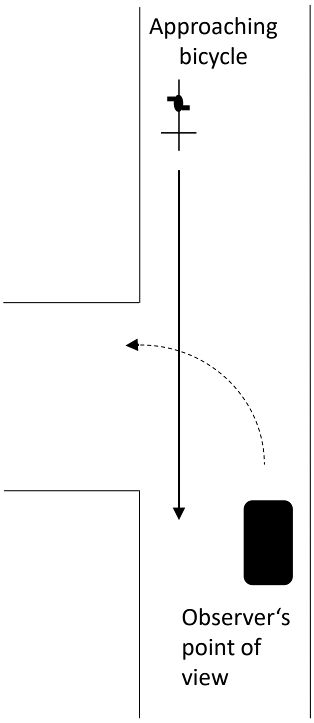

Figure 3: Bird's eye view of the intersection. The solid line represents the trajectory of the approaching cyclist. The dotted line represents the observer's hypothetical left-turn trajectory.

2.2.5. Analysis

For a description of the overall accuracy of the participants' responses (i.e., absolute error), figures 4 to 6 display mean estimated TTA for the three TTA levels. For inferential statistics, we collapse the data across TTA levels since these levels were only introduced to provide some variation in the material and to avoid undesired learning effects. To collapse the data across TTA levels, a transformation of the raw estimates was necessary. For the transformation, we calculated a TTA estimate ratio, which was the proportion of estimated TTA relative to the actual TTA (e.g. Schiff and Oldak, 1990):

$$\text{TTA estimate ratio} = \text{estimated TTA} / \text{actual TTA}$$

A value above 1 indicates an overestimation of the TTA and a value lower than 1 indicates an underestimation. We found no significant differences between the TTA estimate ratios of the different levels ($F\ (2, 84) = 2.19$, $p = .118$, $\eta^2_p = 0.050$) so we then created a single composite score for the main analysis, which was the mean of the three ratios. With the remaining factors, we conducted a four-factor analysis of variance (ANOVA) for mixed designs. Bonferroni correction was used for all pairwise comparisons.

2.3. Results

In Figures 4, 5, and 6, participants' actual TTA estimates are illustrated. As can be seen from the graphs, TTA estimates increased with increasing speed, although the objective TTA was the same. This impression was confirmed by the ANOVA based on the TTA ratios (see Table 3 for an overview of all main effects and interactions). Pairwise comparisons showed significant differences between all three speed levels (all $p < .001$).

Contrary to our previous assumption, actual TTA estimates for the older cyclist were shorter than for the younger cyclist at each of the three TTA levels (Figure 4). The ANOVA indicated significantly lower TTA ratios for the older cyclist ($M = 0.60$; $SD = 0.29$) than for the younger cyclist ($M = 0.65$; $SD = 0.31$).

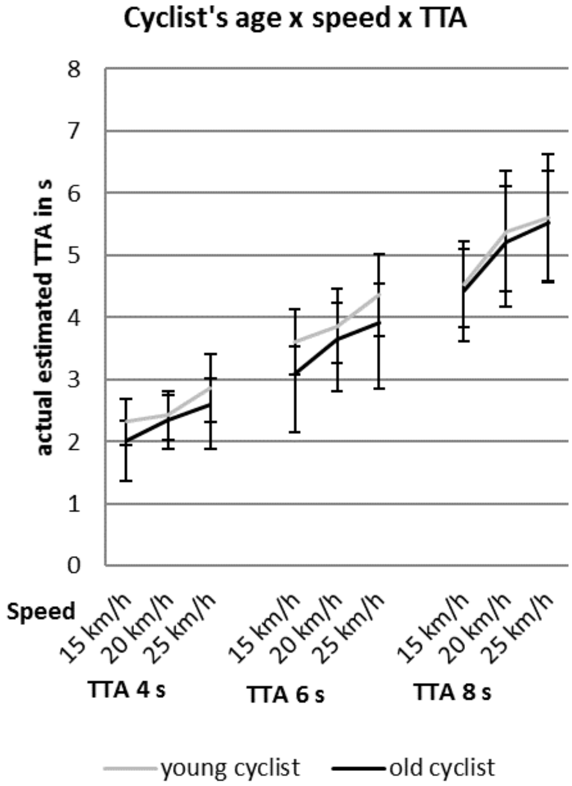

Figure 4: TTA estimates for the different speed levels dependent on cyclists' age. Error bars represent 95% confidence intervals.

Also somewhat surprisingly was we found a significant difference between the two bicycle types (Figure 5), with TTA estimate ratios for the conventional bicycle significantly lower (*M* = 0.61; *SD* = 0.30) than for the e-bike (*M* = 0.64; *SD* = 0.32). There was also a significant interaction between bicycle type and the cyclist's age. The lowest TTA ratios were measured for the older rider on a conventional bicycle (*M* = 0.57; *SD* = 0.29) whereas there were practically no differences between the other three rider-bicycle combinations ($M_{ebike\text{-old}}$ = 0.63, *SD* = 0.31; $M_{ebike\text{-young}}$ = 0.64, *SD* = 0.34; $M_{bicycle\text{-young}}$ = 0.65, *SD* = 0.33).

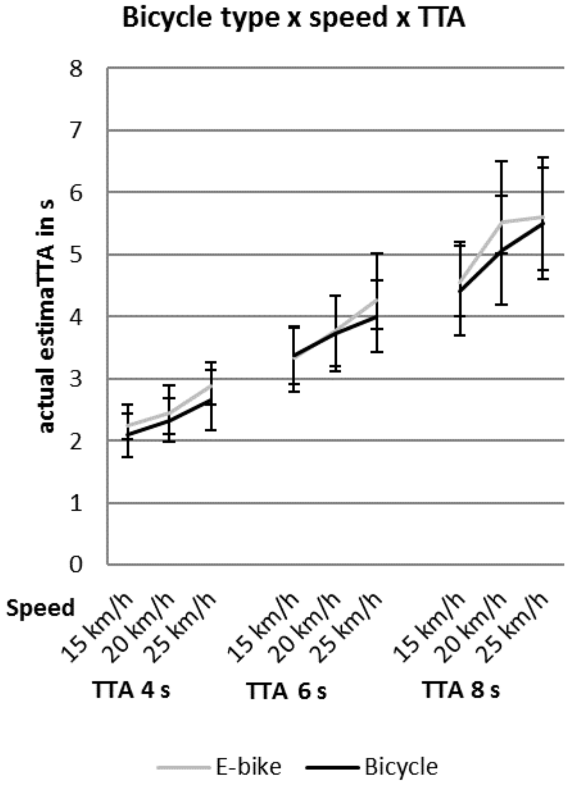

Figure 5: TTA estimates for the different speed levels dependent on bicycle type. Error bars represent 95% confidence intervals.

The observers' age had a significant influence on TTA estimates as well. Older participants provided substantially shorter TTA estimates than the younger participants (Figure 6). The ANOVA revealed significantly lower TTA ratios for the older group (M = 0.45, SD = 0.17) compared to the younger group (M = 0.80, SD = 0.32). In addition, we found a significant interaction between observer age and age of the cyclist. The data show that while older participants did not really differentiate between the two riders (M_{old} = 0.44, SD = 0.16; M_{young} = 0.46, SD = 0.17), the younger participants judged the older cyclist (M = 0.77, SD = 0.30) as arriving considerably earlier than the younger cyclist arrived (M = 0.83, SD = 0.33). Likewise, a significant interaction between speed and observer age was found. For the younger group, the TTA estimate ratios rose more steeply with increasing speed ($M_{\text{young 15}}$ = 0.71, SD = 0.26; $M_{\text{young 20}}$ = 0.81, SD = 0.36; $M_{\text{young 25}}$ = 0.88, SD = 0.37) in comparison to the TTA estimate ratios of the older group ($M_{\text{old 15}}$ = 0.40, SD = 0.16; $M_{\text{old 20}}$ = 0.45, SD = 0.16; M_{old25} = 0.50, SD = 0.18). In addition, we found a significant interaction between speed, cyclist's age, and bicycle type, for which no meaningful interpretation was possible.

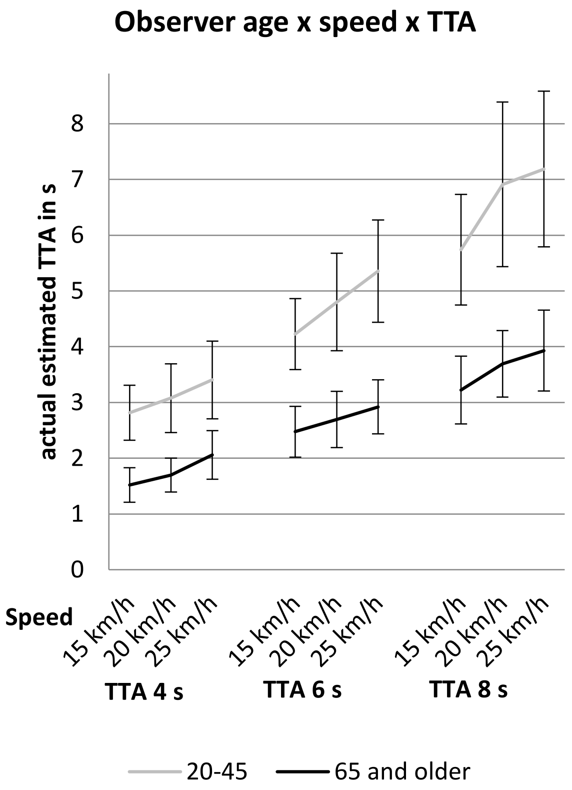

Figure 6: TTA estimates for the different speed levels dependent on observer age. Error bars represent 95% confidence intervals.

Table 3: Summary of ANOVA results for TTA estimate ratio (significant effects in boldface).

	df	*F*	*p*	η_p^2
bicycle type	**1, 42**	**7.67**	**.008**	**.154**
cyclists' age	**1, 42**	**20.01**	**<.001**	**.323**
speed (*GGc)	**1.515, 63.637**	**41.60**	**<.001**	**.498**
observers' age	**1, 42**	**20.91**	**<.001**	**.332**
bicycle type * observers' age	1, 42	.10	.753	.002
cyclists' age * observers' age	**1, 42**	**5.00**	**.031**	**.106**
speed * observers' age	**2, 84**	**3.30**	**.042**	**.073**
bicycle type * cyclists' age	**1, 42**	**11.19**	**.002**	**.210**
bicycle type * speed (*GGc)	1.638, 68.791	.32	.687	.007
cyclists' age * speed (*GGc)	1.647, 69.192	.86	.410	.020
bicycle type * cyclists' age * observers' age	1, 42	.13	.724	.003
bicycle type * speed * observers' age	2, 84	2.54	.085	.057
cyclists' age * speed * observers' age	2, 84	.72	.491	.017
bicycle type * cyclists' age * speed (*GGc)	**1.645, 69.075**	**6.46**	**.005**	**.133**
bicycle type * cyclists' age * speed * observers' age	2, 84	.49	.614	.012

Note: *GGc = Greenhouse-Geisser correction

3. Experiment II

The finding in Experiment I, that the e-bike was judged as arriving later than the conventional bicycle, was somewhat surprising since the two bicycles were chosen to be as similar as possible in terms of their design. From the video, it was impossible to differentiate between them (this was confirmed by the participants). Consequently, a possible explanation for this effect does not lie in the observers' perception of the bicycle, but its rider instead. It appears that human perception is especially attuned for the biological motions of others (Johansson, 1973; Vanrie and Verfaillie, 2004). This perception of motion is often used to infer states, traits, intentions, and future actions of the observed. Schmidt and Färber (2009), for example, provided evidence that drivers use pedestrians' posture and movement to infer a crossing intention. They noted that "there appears to be something special to the human motion which is necessary for intention recognition" (p. 307). Hemeren et al. (2014) found similar results for the prediction of cyclists' behavior.

With the e-bike providing pedaling support to the rider, the riders' effort, and especially his pedaling frequency, decreases when compared to riding a conventional bicycle at the same speed. An observer might interpret this comparatively low effort as an indicator for lower speed. This might also explain the finding that the older rider was perceived as arriving earlier than the younger one. During a second inspection of the video material the impression arose that, not surprisingly, it seemed like the older rider expended much more effort than the younger rider did to achieve the same speed. The observers might have interpreted this increased effort as an indicator for a somewhat higher speed. Because of the findings of Experiment I, the aim of Experiment II was to assess the effect of pedaling frequency on estimated TTA.

Assuming that the perceived rider effort, and not the bicycle type (or the rider's age), was responsible for the findings of the first experiment, the effect of bicycle type should disappear when we control for pedaling frequency. Aside from pedaling frequency and bicycle type, we also varied approach speed and observer age, again expecting longer estimates with increased speed and shorter estimates from older observers.

3.2. Method

3.2.1. Participants

Participants consisted of 22 younger (20-45 years, *M* = 33.0, *SD* = 7.8) and 22 older adults (≥ 65 years, *M* = 71.3 years, *SD* = 3.7). Twenty- two participants were male and twenty-two were female (20-45 years: 9 male, 13 female, ≥ 65 years: 13 male, 9 female). All participants had normal or corrected-to-normal visual acuity and all of them had a valid driving license. Like in Experiment I, participants received monetary compensation for their participation.

3.2.2. Experimental design

Table 4 displays the factors and factor levels of this experiment. The mixed design again included observer age as a between-subjects factor. The three speed levels, two vehicle types, and three TTAs (which were again included only to avoid learning effects) were identical to Experiment I. As a new factor, we introduced a variation of pedaling frequency (two levels). This resulted in a total of 36 within factor level combinations that were then presented randomly to the participants. As dependent variable, we again measured the participants' estimation of TTA.

Table 4: Overview of all factors and factor levels.

Observer age	Bicycle type	Pedaling frequency (Metronome speed)	Speed	TTA
20-45 years	conventional bicycle	Low (90 beats / minute)	15 km/h	4 s
≥ 65 years	electric bicycle	High (155 beats / minute)	20 km/h	6 s
			25 km/h	8 s

3.2.3. Material

The video material used in this experiment was comparable to that used in Experiment I. Again, we recorded a cyclist approaching; he was riding one of the two bicycle types at one of the three speed levels. The two different levels of pedaling frequency were created with the help of a metronome that was played to the rider through an MP3 player. The metronome produced either 90 beats per minute (low condition) or 155 beats per minute (high condition), with the cyclist required to complete half a revolution per beat. Videos were again cut into 4s clips with the bike approaching at one of the three TTA level times. The videos were again presented to the participants by a projector (projection image 125 x 220 cm) with a distance of 250 cm between the participant, who was sitting at a desk, and the screen. The visual angle of the oncoming bicycle, including the rider, ranged from 1.76° to 4.67° (final video frame before occlusion, Table 5).

Table 5: Overview over all factors and factor levels.

Speed	TTA	Visual angle
15 km/h	4 s	4.67°
	6 s	3.42°
	8 s	2.70°
20 km/h	4 s	3.74°
	6 s	2.80°
	8 s	2.18°
25 km/h	4 s	3.22°
	6 s	2.39°
	8 s	1.76°

3.2.4. Procedure

The experimental procedure and room were the same as in Experiment I. Participants were presented with instructions and two practice trials before they began the 36 experimental trials. Again, their task was to indicate the arrival of the bicycle at the white line by pressing the space bar. The entire session lasted 15 to 20 minutes.

3.2.5. Analysis

The analysis procedure was identical to the one in Experiment I. Since we found no significant differences regarding the TTA estimates between the different TTA levels, F (2, 84) = 3.24, p = .051, η^2_p = 0.072, we collapsed the data across TTA levels for the main analysis. A 4 factor mixed-design ANOVA was conducted for the TTA estimates ratio and Bonferroni correction was used for the pairwise comparisons.

3.3. Results

Figures 7, 8, and 9 display the actual estimated TTAs of the cyclists' speed for each of the TTA levels depending on the factors bicycle type, pedaling frequency, and observer age. Like Experiment I, the effect of the cyclists' speed on TTA estimates was statistically significant (see Table 6 for an overview of all main effects and interactions), with higher speeds being associated with increased TTA estimates. Pairwise comparisons revealed significant differences between all three speed levels (all $p < .001$).

Bicycle type (Figure 7), on the other hand, was no longer significantly associated with TTA ratios, with nearly identical mean TTA ratio values for the conventional bicycle ($M = 0.75$, $SD = 0.40$) and the e-bike ($M = 0.76$, $SD = 0.38$). However, there was an interaction between bicycle type and speed. For 15 and 20 km/h, the TTA estimates, as well as the ratios, were lower for the conventional bicycle than for the e-bike ($M_{\text{bicycle 15}} = 0.66$, $SD = 0.37$; $M_{\text{bicycle 20}} = 0.73$, $SD = 0.39$; $M_{\text{e-bike 15}} = 0.68$, $SD = 0.37$; $M_{\text{e-bike 20}} = 0.78$, $SD = 0.40$), whereas for 25 km/h, the TTA estimates ratios were lower for the e-bike than for the conventional bicycle ($M_{\text{bicycle 25}} = 0.86$, $SD = 0.47$; $M_{\text{e-bike25}} = 0.83$, $SD = 0.39$).

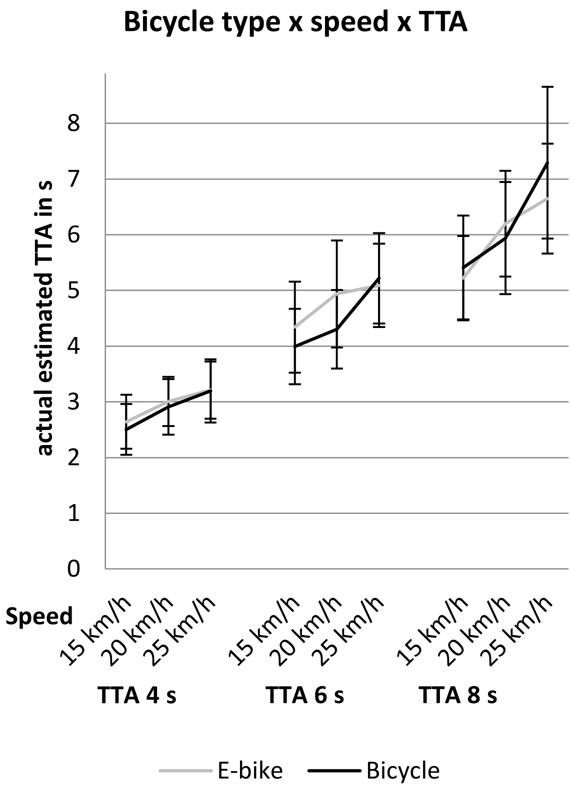

Figure 7: TTA estimates for the different speed levels by bicycle type. Error bars represent 95% confidence intervals.

While bicycle type no longer played a main effect role in TTA estimates, we found a significant main effect of pedaling frequency. The actual estimated TTA for the higher pedaling frequency was clearly shorter than the estimates for the lower frequency (Figure 8). As a consequence, the TTA ratio for the higher pedaling frequency was significantly smaller (*M* = 0.72, *SD* = 0.38) than for the lower pedaling frequency (*M* = 0.79, *SD* = 0.41), i.e., participants perceived a bicyclist with a higher pedaling frequency as arriving earlier compared to a cyclist with a lower frequency. As expected, the age of our participants had a significant effect as well (Figure 9); the TTA ratios for our older group of participants were much lower (*M* = 0.51, *SD* = 0.15) than the TTA ratios for our younger group of participants (*M* = 1.01, *SD* = 0.40).

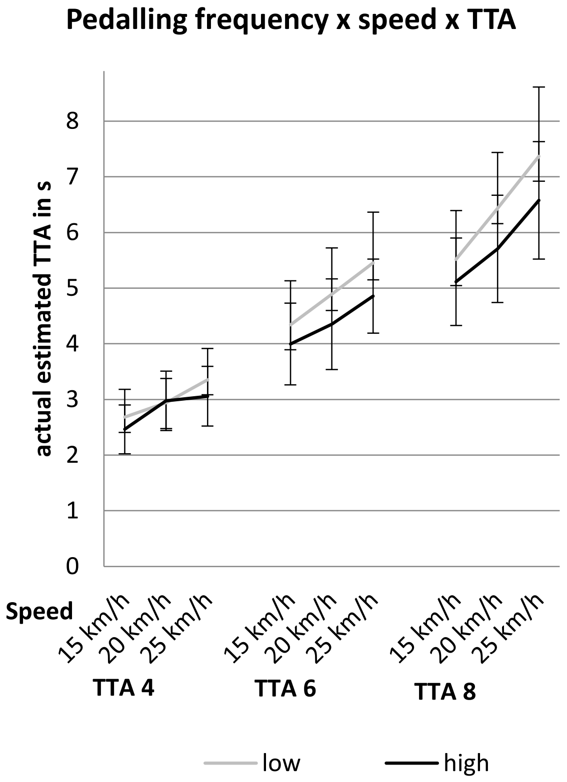

Figure 8: TTA estimates for the different speed levels by pedaling frequency. Error bars represent 95% confidence intervals.

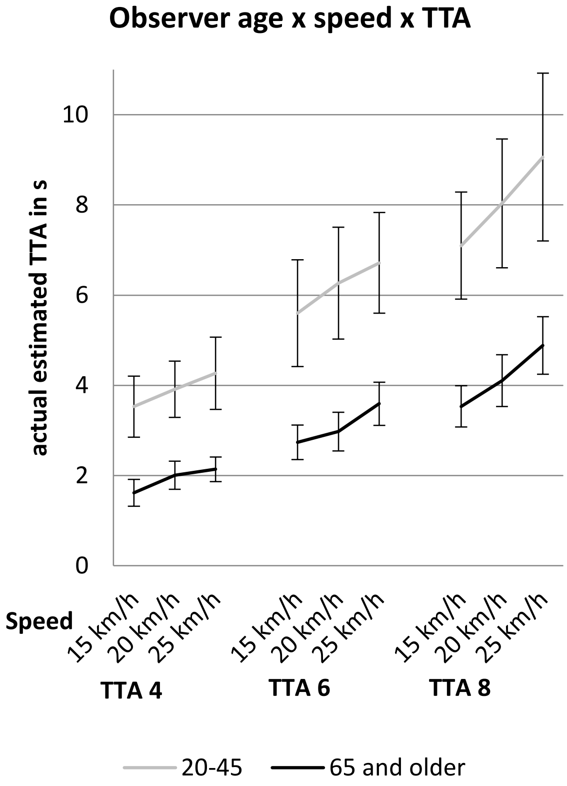

Figure 9: TTA estimates for the different speed levels by observers' age. Error bars represent 95% confidence intervals.

Table 6: Summary of ANOVA results for TTA estimate ratio. Significant effects in boldface.

	df	*F*	*p*	η_p^2
bicycle type	1, 42	2.88	.097	.064
pedaling frequency	**1, 42**	**32.67**	**< .001**	**.438**
speed (*GGc)	**1.604, 67.383**	**100.22**	**< .001**	**.705**
observer age	**1, 42**	**30.47**	**< .001**	**.420**
bicycle type * observer age	1, 42	.03	.876	.001
pedaling frequency * observer age	1, 42	2.18	.148	.049
speed * observer age	2, 84	2.85	.064	.063
bicycle type * cadence	1, 42	.01	.949	.000
bicycle type * speed (*GGc)	**1.755, 73.722**	**3.99**	**.027**	**.087**
pedaling frequency * speed (*GGc)	1.719, 72.197	1.14	.320	.026
bicycle type * pedaling frequency * observer age	1, 42	.01	.908	.000
bicycle type * speed * observer age	2, 84	1.72	.185	.039
bicycle type * pedaling frequency * speed	2, 84	.19	.825	.005
pedaling frequency * speed * observer age	2, 84	1.20	.307	.028
bicycle type * pedaling frequency * speed * observer age	2, 84	.01	.997	.000

Note: *GGc = Greenhouse-Geisser correction

4. Discussion and conclusions

We conducted two experiments examining the TTA estimations of approaching bicycles, in which approach speed, bicycle type, cyclist's age, pedaling frequency, and observers' age were tested as influencing factors on TTA judgments. Experiment I showed a large effect of the cyclist's approach speed, observer's age, cyclist's age, and bicycle type on TTA estimation. The results for bicycle type suggested that the perception of the rider's motion had an effect on the TTA estimates since the e-bike, although visually indistinguishable from the conventional bicycle, was judged as arriving significantly later. It was hypothesized that the reduced cycling effort when riding an e-bike, e.g. through a reduced pedaling frequency, might be the source of this difference in perception. This hypothesis was tested in Experiment II. Indeed, the results showed a large effect of pedaling frequency on TTA estimations; cyclists approaching with a higher pedaling frequency were judged to be arriving earlier than cyclists pedaling with a lower frequency are. Moreover, the effect of pedaling frequency was independent of bicycle type, i.e., for both, the e-bike and the conventional bicycle, higher pedaling frequencies were associated with shorter TTA estimates. At the same time, there was no longer an effect of bicycle type on participants TTA estimates. This result underlines the relevance of the cyclist's motion pattern for TTA estimation.

In both experiments, we found that the age of the observer had a strong effect on TTA estimates, with older participants consistently providing shorter estimates than younger observers did. This finding confirms results from previous studies (e.g. DeLucia et al., 2003; Hancock and Manser, 1997; Schiff et al., 1992). Unfortunately, although this finding should mean that older participants make safer decisions on the road (Scialfa et al., 1987), DeLucia et al. (2003) found no correlations between TTA judgments and driver performance measures. Based on further results, they argued that older drivers have problems judging whether or not a collision would even occur, because they have problems accounting for the trajectory of the approaching object. This, in their interpretation, could be one potential explanation for the increased crash rates of older drivers.

The results from both experiments make it clear that approach speed has a considerable impact on TTA estimates, with increases in speed resulting in longer TTA estimates. While similar findings have been reported in regards to TTA estimates for motorized vehicles (e.g. Horswill et al., 2005; Manser, 1999), our results are the first to confirm these findings for the cycling domain with its comparatively slower speeds. In addition, the fact that our relatively minor speed variations (in steps of 5km/h) still provoked this effect is an indicator for the stability of the phenomenon. This might be seen as slightly alarming, since the close link between TTA estimate and crossing decision (Petzoldt, 2014) implies that riders of e-bikes, with their potential to travel at higher speed, should be considered as being at an increased risk for collisions.

This issue is further complicated by the fact that approaching e-bikes were judged as arriving later than conventional bicycles. As Experiment II showed, this effect is mainly driven by a perceived reduction in effort by the cyclist, due to a reduced pedaling frequency. The interpretation that perceived pedaling effort is an indicator of the cyclist's speed also helps explain the apparently counterintuitive finding that the older cyclist was perceived to have arrived earlier than the younger one. The situation in which an e-bike rider approaches another party with seemingly low effort, but at relatively high speeds, must therefore be considered a situation prone to misperception by the other party.

Additional problems arise when comparing bicycles (in general) to other vehicles. It has repeatedly been reported that larger vehicles (e.g. Caird and Hancock, 1994), and larger objects in general (e.g. DeLucia, 1999; van der Kamp et al., 1997), are judged to arrive earlier than smaller ones. This so called size-arrival-effect has even been suspected to be the cause of a considerable number of car drivers' right-of-way violations in interactions with motorcycles (Horswill et al., 2005). As cyclists and their bicycles are probably physically the smallest group of road users, it has to be assumed that the high number of turning crashes between motorized vehicles (mainly those with four wheels) and cyclists are also a result of TTA overestimations. Overall, these findings indicate that there is no simple solution to the problem of a potential misperception regarding the TTA estimate of an e-bike rider.

A first step towards such a solution might be to increase road user awareness of the fact that there is a growing presence of vehicles on the road that might look like conventional bicycles, but are possibly travelling much faster. Road safety organizations should take on the responsibility of educating other road users about electric bicycles and their capabilities (Bohle, 2015). Unfortunately, currently e-bike users themselves also have to be prepared that other road users might be unaware of the presence of e-bikes on the road, and thus should expect unsafe turning or crossing maneuvers in front of them.

A step beyond the mere provision of more information would be to increase the distinctiveness of e-bikes through design changes, to allow for a better differentiation between them and conventional bicycles. It is clear that road users are hardly able to visually distinguish between conventional bicycles and e-bikes, which is a problem. The view of a certain vehicle leads road users to form expectations about this vehicle's behavior, including its acceleration and speed (Cherry and Andrade, 2001; Davies, 2009). Such expectations help to ease the decision making process. E.g., knowing that bicycles are usually rather slow helps to make a crossing decision in which a bike is in a considerable distance, without the need to actually observe the bicycle's approach. After all, given its limitations, there should be no chance that the bicycle is so fast that a collision would be even possible. However, the behavior of e-bikes does not necessarily match such expectations. Therefore, it appears necessary to make it clear to other road users that the bicycle-shaped vehicle that is coming towards them is, in fact, not a conventional bicycle. While such an approach would not eliminate the size-arrival-effect, it would reduce judgmental errors that occur because road users erroneously assume that the vehicle coming towards them is an ordinary bicycle when in fact it is an e-bike. In addition, it might be assumed that, once the market penetration of e-bikes is high enough so that other road users have been able to experience them on a regular basis, their speed should no longer come as a surprise. However, given the persistence of the effects of speed or size of vehicles in general on TTA estimates, it is unrealistic to expect a clearer differentiation or an increase of exposure to fully eradicate any apparent misperceptions of an e-bikes approaching speed. The fact that differences in TTA estimation can still be found for long established vehicle types suggests that the unfavorable effects we found for e-bikes will not completely disappear, regardless of the measures that might be taken.

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