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Drivers' gap acceptance in front of approaching bicycles – Effects of bicycle speed and bicycle type

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ABSTRACT

The growing popularity of electric bicycles gives rise to a variety of road safety questions. One of the issues is e-bikes' potential to achieve a higher speed compared to conventional bicycles. Especially for road users that are unfamiliar with that type of bicycle, underestimations of speed might be suspected which could lead drivers to accept unsafe gaps (e.g. for turning manoeuvres) in front of approaching e-bikes. But also higher speed as such might prove problematic, as previous studies have shown repeatedly that drivers tend to choose smaller time gaps in front of vehicles approaching at higher speed. Forty-two drivers (two age groups) were recruited to investigate their gap acceptance behaviour on a test track. Participants were seated in a car, waiting to enter traffic, which would have required crossing a lane on which a cyclist approached. Cyclists approached at speeds between 15 and 35 km/h and rode either a conventional bicycle or an e-bike. Participants were instructed to press a foot pedal to indicate the last moment at which they would be willing to enter traffic in front of the bicyclist. Results show that with increasing cyclist speed, accepted time gaps became significantly shorter. At the same time, participants appeared to select shorter time gaps when the approaching bicycle was an electric one, even though the two different bicycle types could not be distinguished from the participants' position. Although we found only few accepted gap sizes that would have been especially risky, the findings indicate that the effect of bicycle speed has to be considered when discussing the consequences of an increased e-bike prevalence for road safety.

1. Introduction

Electric bicycles have seen a steep rise in popularity in the last decade (Rose, 2012). Sales figures in Germany (Zweirad-Industrie-Verband, 2013) and other European nations are growing, and are expected to continue to grow (Zweirad-Industrie-Verband, 2011). In China, e-bike sales figures reached 10 million per year already in 2005 (Weinert et al., 2007). In general, this development is welcomed, as cycling, also on e-bikes, is considered a healthy, environmentally friendly mode of transport. Previous studies also indicate that a lot of e-bike users do not necessarily use it as a substitute for a conventional bike, as it has been reported that the length of trips made with an e-bike was considerably longer (Cherry and Cervero, 2007). It appears that the e-bike is often a substitute for public transport (An et al., 2013) or a car (Popovich et al., 2014). In addition, a lot of elderly cyclists that would otherwise not be able to ride a conventional bike because of their physical condition can continue to cycle (Dill and Rose, 2012; Parker, 2006). It has been found that even elder citizens that gave up cycling previously are getting back onto the road on e-bikes (Alrutz, 2013). In terms of promoting healthy and environmentally friendly mobility, the trend towards e-bikes might be embraced unequivocally.

However, as more and more e-bikes are on the road today, road safety concerns have been voiced. Chinese accident statistics (Feng et al., 2010) show that the rate of crashes that involve e-bikes has risen continuously in recent years (however, it has to be acknowledged that the Chinese definition of e-bike is much wider than the European one). Data from Switzerland, where e-bikes are listed as a separate category of road user in the accident statistics since 2011, point in a similar direction (Achermann Stuermer et al., 2013). Especially worrisome is the fact that accident severity appears to be higher than for conventional bicycles.

In this context, one aspect that has been questioned is how other road users cope with the fact that there now is something

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on the road that looks like a normal bicycle, however accelerates much faster, and reaches quite different speed levels than a conventional bicycle. In a German survey of e-bike riders, one of the potentially hazardous situations that the cyclists considered relevant was the underestimation of their speed by a motorised vehicle (Alrutz, 2013). Schleinitz et al. (2014) showed that e-bikes reach higher mean speeds, and also travel for longer proportions of their trips at speeds beyond 20, 25 and 30 km/h. Similar results have been reported by others (Cherry and He, 2009; Hacke, 2013).

It has been found previously that vehicle approach speed influences drivers' gap acceptance behaviour. Already in 1977, turning manoeuvres at a T-junction were observed in order to gain insight into the effect of speed on gap acceptance (Cooper et al., 1977). The analysis showed an effect of speed (which varied between 27.5 mi/h and 42.5 mi/h – i.e. 44.2 km/h and 76.5 km/h) on the size of accepted time gaps, with smaller gaps being accepted with increasing speed. Alexander et al. (2002) let participants drive in a driving simulator and required them to complete right turn manoeuvres (be aware that this study is from the UK, i.e. the situation equals a left turn manoeuvre in most other countries). Participants were instructed to stop at the intersection, and make a turn across a lane with oncoming traffic when they considered it safe to do so. The oncoming cars approached at either 30 mi/h (approximately 48.3 km/h) or 60 mi/h (approximately 96.6 km/h). The results showed that drivers tended to accept gaps that were on average 2 s smaller when the approaching vehicle was travelling faster. Similar results have been reported from another driving simulator study (Yan et al., 2007), in which participants were required to turn left (in a right hand driving environment) into the traffic stream. Here, the accepted gaps at the higher speed level were about 1.6 s smaller than the ones accepted at lower speed. The tendency to accept smaller gaps when the approaching vehicle is faster appears to be relatively stable, and has been found also for pedestrian crossing decisions (Lobjois and Cavallo, 2007; Oxley et al., 2005; Petzoldt, 2014).

In addition to vehicle approach speed, a number of other aspects have been reported to influence the size of the accepted gaps, such as the type of the oncoming vehicle (Bottom and Ashworth, 1978) or the observing drivers' gender (Alexander et al., 2002; Yan et al., 2007). One central factor is drivers' age. A common finding is that younger drivers tend to accept smaller gaps than older motorists (Alexander et al., 2002; Yan et al., 2007). Interestingly, the effect of speed is often more pronounced in older drivers, i.e. the size of the accepted gaps differs much more between different speed levels (Yan et al., 2007). One potential explanation that has been provided for this interaction between age and approach speed is that older drivers appear to "overestimate at lower speeds and underestimate at higher speeds" (Scialfa et al., 1991).

Most of the effects described above are a direct reflection of effects found for time to collision (TTC)/time to arrival (TTA) judgments. The estimation of the time it takes an object to arrive at a certain predefined position is often argued to underlie road users' decisions and behaviour (e.g., Rock and Harris, 2006; Stewart et al., 1993). Probably the most prominent theoretical assumption on how such an estimation is made is the so called tau-hypothesis (Lee, 1976). Following this hypothesis, the perception of TTC is direct and does not require additional processing of, e.g., object size or distance. However, since "tau-theory has become one of the best researched topics in perceptual psychology" (Hecht and Savelsbergh, 2004; p. 1), it has become clear that there is more to TTC estimation than just the observation of optical expansion.

One of the most replicated findings is that there is a positive correlation between object approach speed and participants' TTC estimates (e.g., Hancock and Manser, 1997; Manser and Hancock, 1996; Oberfeld and Hecht, 2008; Schiff et al., 1992; Schiff and Oldak, 1990). The explanation provided for this effect is that, to some degree, observers rely on physical distance to make estimates of TTC, a phenomenon that has been described as distance bias (Law et al., 1993). Petzoldt (2014) was able to show that the effect of approach speed on the gap size accepted by pedestrians can be explained mainly with this effect.

Age effects have been found for judgments of TTC, too. Usually, it is reported that older observers are less accurate than younger ones in estimating TTC. What this phrasing of the findings fails to acknowledge is that in most cases, this lower accuracy is actually a systematic bias towards lower estimates, i.e. older observers show a strong tendency to underestimate TTC (Hancock and Manser, 1997; Petzoldt, 2014; Schiff et al., 1992). This, at least partially, can serve as an explanation for the differences in accepted gap size between different age groups.

Unfortunately, (applied) TTC studies and gap acceptance studies alike mostly focused solely on situations in which judgments or decisions in relation to motorised vehicles were required. The vehicle approach speeds investigated were usually 40 km/h or higher. One exception is Te Velde et al.'s (2005) study of pedestrian crossing behaviour when confronted with an oncoming bicycle (however, with a maximum speed of just 6.5 km/h). If the effect of speed on accepted gap size can also be found at speed levels that are typical for bicycles is, at this stage, unclear. Also, the differences between the investigated speed levels were often rather high, leaving open the question of whether rather subtle differences in speed, as they would be expected between conventional bicycles and e-bikes, would be perceived and acted upon.

Aim of the experiment presented in this paper was to investigate what gap sizes drivers choose when confronted with an oncoming cyclist. The experiment was conducted on a test track, where participants seated in a car were supposed to indicate their minimum acceptable gap when asked to turn in front of an approaching bicycle.

Of primary interest was the effect of the cyclist's speed on the accepted gaps, and whether it matters if the approaching vehicle is a conventional bicycle or an e-bike. Based on the reported findings, we hypothesised that a higher approach speed would result in smaller accepted time gaps. The inclusion of bicycle type was of explorative character. Given that vehicle-related differences in gap acceptance have usually been linked only to vehicle size, we did not expect to find differences between conventional bicycles and e-bikes.

In addition, we manipulated the road gradient and the observers' perspective. Gradient appeared to be an interesting factor as the use of an e-bike allows its user to achieve speed levels when riding uphill which, with a conventional bicycle, are usually only achieved on flat sections of road. As common sense suggests, and data from Schleinitz et al. (2014) show, cyclists are slower when riding uphill compared to their average cycling speed. If drivers use this knowledge for their gap acceptance decisions, they should be more willing to turn in front of a bicycle that is approaching uphill, i.e., we should expect smaller accepted gaps under this condition.

With regard to the observers' perspective, we assumed that a side view might allow for a somewhat better estimate of the approaching cyclists speed. It has been suggested that a certain degree of eccentricity when observing an oncoming object would lead to better judgments of its approach (Schiff and Oldak, 1990). A side view might provide sufficient eccentricity, whereas a frontal view would certainly not. However, it was not clear what effect such a better judgment of approach would have on gap acceptance, so we did not formulate a specific hypothesis.

Finally, to account for the widely reported age effects, we investigated two different age groups. We expected younger drivers to