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Can a unique appearance of e-bikes, coupled with information on their characteristics, influence drivers' gap acceptance?

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ABSTRACT

Objective: Earlier studies have shown that, when confronted with approaching e-bikes, car drivers tend to underestimate their speed and accept smaller gaps for crossing in front of them compared to conventional bicycles (Petzoldt et al. 2017b; Schleinitz et al. 2016b). As an explanation, it has been suggested that car drivers rely on their previous experience with conventional bicycles, which tells them that those mostly travel at low speeds. E-bikes, which look just like regular bicycles, do not conform to this expectation, resulting in potentially dangerous interactions. Based on this assumption, researchers have suggested to increase other road users' awareness of e-bikes' higher speeds by giving them a distinct appearance. The goal of our experiment was to investigate the effects of such a unique appearance, aided by clear instructions about the higher speeds of e-bikes, on gap acceptance.

Method: In order to investigate the effect of appearance independent of the effect of bicycle type, we used video sequences of conventional bicycles and e-bikes approaching at different levels of speed. The riders (regardless of what type of bike they were actually riding) either wore an orange helmet as an indicator for an e-bike, or a grey helmet indicating a conventional bicycle. Fifty participants were asked to indicate the smallest acceptable gap for a left turn in front of the cyclist or e-bike rider.

Results: The results showed significantly smaller acceptable gaps when confronted with the grey helmet (signal for bicycle) compared to the orange helmet (signal for e-bike), whereas there was no difference between the actual bicycle types.

Conclusions: Overall, the results indicate that informing about e-bikes characteristics in combination with a unique appearance can lead to a more cautious behaviour among car drivers.

Keywords: time to collision, gap acceptance, electric bicycle, speed judgements.

INTRODUCTION

As the number of e-bikes is growing considerably on roads all over the world (Confederation of European Bicycle Industry 2017; Rose 2012), new problems for traffic safety arise. Various studies have shown that e-bike riders travel at higher speeds than conventional cyclists (Huertas-Leyva et al. 2018; Schleinitz et al. 2017; Vlakveld et al. 2015). It has been suggested that this could cause safety critical situations, as other road users might misperceive an e-bike for a conventional bicycle, and as a consequence, underestimate its speed (Jellinek et al. 2013; Popovich et al. 2014; Scaramuzza et al. 2015). This is corroborated by e-bike riders themselves, one of whom explained that "you ride faster on an e-bike and often car drivers are not aware of that. Especially, when drivers intend to turn right they think they can manage before one comes past on a bike. I experienced that twice, where I had to break [sic] heavily" (Haustein and Møller, 2016).

As an explanation for the misperception of e-bikes' speed, it has been suggested that other road users have learned that bicycles mostly travel at low speeds (Haustein and Møller, 2016). Based on prolonged experience, road user build heuristics – rules of thumb - about characteristics of vehicles. For example, it has been shown that observers tend to judge specific car types as being faster than others (Davies 2009, Davies and Patel 2005). If a new vehicle type is introduced, no heuristics based on previous experience exist, which, in theory, should result in a more careful behaviour of other road users around such a vehicle, and a more thorough observation and information processing. In the case of the e-bike, however, there are heuristics available for a vehicle that looks like an e-bike - a conventional bicycle - however has different behavioural characteristics (low speed, low acceleration). The fact that e-bikes do not conform to the expectation of low speed and acceleration can therefore result in potentially dangerous interactions with other road users and a higher crash risk. Indeed, when confronted with an approaching e-bike, car drivers tend to underestimate their speed and accept smaller gaps for turning in front of them in comparison to conventional bicycles (Petzoldt et al. 2017b; Schleinitz et al. 2016b). The authors argued that drivers relied on their previous experience with bicycles, which led them to assess speed (to some degree) based on easily observable features such as pedalling frequency or posture (as an indicator of effort), a strategy that is misleading in the case of the e-bike, which allows for rather effortless cycling with comparatively low pedalling frequencies. Indeed, when manipulated experimentally, pedalling frequency, and not bicycle type, was found to have an effect on estimated gap size (Schleinitz et al. 2016b). The issue is complicated further by the fact that approach speed as such already has an impact on accepted gap size, with smaller gaps being accepted with increasing speed (Alexander et al. 2002; Cooper et al. 1977). Likewise, it has been found that vehicle size has an effect on drivers' gap acceptance, with smaller gaps being accepted for smaller vehicles (Alexander et al. 2002; Keskinen, et al. 1998).

Of course, it can be assumed that, after a longer period of exposure to and experience with e-bikes, other road users would adapt, i.e. they learn that the vehicle that looks like a bicycle could actually as well be an e-bike, and expect a larger range of speeds and accelerations. Simply relying on this process, however, might be considered somewhat unethical, given the rapid increase of the number of e-bikes on the roads, and the associated increase of crash risk in the short term. Researchers have therefore suggested to increase other road users' awareness of e-bikes' higher speeds by giving them a distinct appearance (Dozza et al. 2016; Huertas-Leyva et al. 2018) or inform them about the higher speeds of e-bikes through campaigns

(Jellinek et al. 2013; Scaramuzza et al. 2015). Both of these aspects are relevant. While the knowledge of e-bike's potential to reach higher levels of speed is vital to form appropriate expectations, it is equally important to be able to distinguish between e-bikes and conventional bicycles, to be able to act on these expectations. While previous attempts have produced only mixed results (Schleinitz and Petzoldt 2017), the general approach of making e-bikes easily recognisable by a unique appearance and informing people about the higher speed of the e-bike as well as their appearance clearly appears to be reasonable.

The goal of our experiment was to investigate the effects of a unique appearance for e-bikes, aided by clear instructions about their potential to reach higher speeds, on drivers' gap acceptance. In order to investigate this independent of the effect of bicycle type, we used video sequences of conventional bicycles and e-bikes approaching at different levels of speed. To create the unique appearance, riders either wore an orange helmet as an indicator for an e-bike, or a grey helmet indicating a conventional bicycle (regardless of what type of bike they were actually riding).

METHOD

Participants

In total 50 participants took part in the experiment (16 males, 34 females). They were on average 22.8 years old (*SD* = 3.8). More than 80% of the participants were students of Chemnitz University of Technology, whereas the other pursued various professions. All of them had a drivers' license, were active drivers and drove on average 5,482 km per year (*SD* = 6,815).They had normal or corrected visual acuity. For their participation, they received monetary compensation.

Experimental design

We conducted a video-based laboratory experiment with scenes of different bicycle types approaching an observer. The videos showed two different bicycle types: a conventional trekking bicycle (Diamant Ubari black) and a comparable e-bike (Diamant Supreme), which approached at constant speeds from 15 to 35 km/h (in 5 km/h increments). In half of the videos, the rider wore either an orange helmet, in the other half a grey one (independent of bicycle type). This resulted in 20 within-factor level combinations (5 speed levels x 2 bicycle types x 2 helmet colours), for which the size of the minimum acceptable gap as indicated by the participants was measured.

Material

Video material was recorded on a straight taxiway of a small general aviation airport. The point of view was that of a driver, i.e. the height of the camera position was comparable to the eye level of a driver sitting in a car. The observer/camera was put at a T-junction, in a position that is similar to a car waiting to make a left turn. A cyclist approached at a constant speed in the oncoming lane across which the left turn would have to be executed. The rider approached either on a conventional bicycle or on an e-bike. The position of a potential collision between the approaching cyclist and the observer's car when turning left was marked by a white line that was pasted onto the road.

After recording, all videos were edited to provide the participants a clear visual differentiation between conventional bicycle and e-bike. In the original video material, the rider wore a grey helmet in all approaches. Within these videos, an orange helmet was "created" with the help of the video editing software Sensarea 1.10.1 (see Figure 1). This was done with all videos for all combinations of speed and bicycle type. This resulted in two sets of videos that were completely identical in all aspects except the colour of the rider's helmet (which was intended as an indicator of whether the rider was approaching on an e-bike or a conventional bicycle).

All videos were cut so that the approaching cyclist was always in a distance of 100 m from the white line at the start of each clip. The video continued until the vehicle had passed the position of the observer, which resulted in variable clip length, dependent on approach speed. The video material was presented on a 23 inch screen. Participants were seated at a desk in a distance of 60 cm.

[Figure 1]

Procedure

At the beginning of the experiment, participants were informed about the differences between e-bikes and conventional bicycles. First, it was explained that e-bikes support the riders while pedalling with an electric motor up to 25 km/h, so that the rider can reach higher speeds than conventional bicycles. Second, they received explicit information that in the videos, the e-bike rider would wear an orange helmet to better distinguish him from the conventional cyclist. After these general instructions, the specific instructions on gap acceptance followed. Participants should put themselves in the position of a car driver at the intersection, waiting to make a left turn. Their task was to indicate the minimum gap that they felt was acceptable to complete a left turn in front of the approaching cyclist. They should indicate the moment the gap between observer and cyclist had reached this critical size by pressing the spacebar. All video clips were shown twice in randomized order, which resulted in 40 trials. The participants completed two practice trials before data collection started. Afterwards, they had to fill in a short questionnaire on demographic variables (e.g. age, gender, distance travelled per year). The experiment lasted about 20 - 30 minutes.

Data analysis

For data analysis, a mean value for minimum accepted gap size was calculated for each factor level combination (helmet colour x bicycle type x speed). The statistical analysis of minimum accepted gap size was conducted using a three-factor analysis of variance (ANOVA) for repeated measurements. Bonferroni correction was used for all pairwise comparisons.

RESULTS

One participant had to be removed from the dataset as he produced implausible values for accepted gap size (gaps of only a few ms). Figure 2 depicts the minimum accepted gap size dependent on helmet colour and approach speed, for the actual bicycle and Figure 3 for the actual e-bike. Table 1 shows the main effects and interactions between the factor combinations as uncovered by the ANOVA. In the appendix, histograms detailing the distribution of responses for the different levels of approach speed and the different helmet colours can be found (Appendix, Figure A1-A5).

As Figure 2 and 3 show, the rider's approach speed had a strong (and significant, see Table 1) impact on minimum accepted gap size, with smaller gaps being accepted at higher approach speeds**.** Post hoc tests revealed significant differences between all speed levels (all $p < .001$). It seems that, while, surely, time to collision (the time remaining until the approaching bicycle would reach the observer) is the single most safety relevant characteristic of the approaching bicycle, it hardly seemed to play a role in observers decisions. There also was a significant main effect of helmet colour, with the accepted gaps for the left turn when the rider wore a grey helmet (supposed conventional bicycle; $M = 7.2$, $SD = 2.6$) being smaller than when the helmet was orange (supposed e-bike; $M = 7.4$, $SD = 2.5$). It appears that participants were willing to accept smaller gaps in front of what they believed was a bicycle, as compared to the supposed e-bike. In contrast, we found no significant effect of actual bicycle type. The accepted gap size in front of the e-bike rider ($M = 7.3$, $SD = 2.6$) and the conventional cyclist ($M = 7.3$, $SD = 2.6$) were identical.

In addition, the ANOVA revealed a significant interaction between helmet colour and speed. As can be seen in Figure 2, the difference between the two helmet colours was reduced, and even disappeared, for the higher speed levels, especially at 35 km/h ($M_{orange\ 35\ km/h} = 5.2$, $SD_{orange\ 35\ km/h} = 1.7$; $M_{grey\ 35\ km/h} = 5.3$, $SD_{grey\ 35\ km/h} = 1.6$).

[Figure 2 and 3]

[Table 1]

For descriptive purposes, we transformed the minimum accepted gap size from a time-based into a distance-based metric (i.e., "how far is the bike away" instead of "when does it arrive"; see Figure 4 and 5). This transformation leaves the main effect of helmet colour untouched (just as the non-effect of bicycle type). Important, however, is the fact that there still is an effect of speed on the distance-based size of the accepted gaps. Although observers did not seem to use time to collision as a basis for their decisions (Figure 2 and 3), they also did not just rely on a certain physical distance. It appears that they, at least to some degree, accounted for the bicycles' approach speed. It should be noted, however, that this relationship does not appear to be fully linear, as especially at the higher speed levels (30 km/h and 35 km/h), the differentiation disappeared.

[Figure 4 and 5]

DISCUSSION

Goal of our experiment was to investigate whether it would be possible to influence drivers' gap acceptance in front of approaching cyclists by introducing different appearances for the cyclists (i.e., helmets of different colours), and linking those appearances to certain characteristics of the bicycle (i.e., e-bike vs. conventional bicycle, and their potential to reach certain levels of speed). Our results show that, independent of which type of bicycle type was actually approaching, minimum accepted gaps were larger in front of the rider that was assumed (based on his appearance) to be riding an e-bike compared to the supposed cyclist, although it should be noted that the difference is less than a second in practice. Still, these results suggest that, in principle, a unique appearance coupled with clear instructions can influence drivers' gap acceptance, so that a more cautious behaviour would be provoked.

In addition, an interaction effect between appearance and approach speed was found, as the effect of the helmet colour on accepted gap size seemed to disappear at higher speed levels. A potential explanation can be derived from investigations of the judgment of time to collision (Cavallo and Laurent 1988; McLeod and Ross 1983), who reported that the judgment improves with higher approach speed. For our experiment, it might be deduced, that, because the assessment of approach speed was easier to accomplish at the higher speed levels, the impact of previous experience on gap acceptance is diminished.

Interestingly, the effect of actual bicycle type that had been found previously (Petzoldt et al. 2017b; Schleinitz et al., 2016b) disappeared. It seems that, when observers are provided with a clear and unambiguous cue as to what type of bicycle is approaching them, the role of other, less reliable cues (e.g., pedalling frequency) is reduced. The unique appearance coupled with information about e-bikes' higher speed apparently overcame the effect of heuristics and prior knowledge on conventional cyclists' speed.

In line with previous studies, an increase in speed led to shorter accepted time gaps in front of the bicycle and the e-bike (Petzoldt et al., 2017b; Schleinitz et al. 2016a), an effect that was much stronger than the effect of the rider's appearance (with a difference of only 0.2s on average). As several studies have shown that e-bikes are indeed used at higher speeds levels than conventional bicycles (Huertas-Leyva et al. 2018; Schleinitz et al. 2017; Vlakveld et al. 2015), a unique appearance might therefore not be fully sufficient to counter a potential increase in crash risk for e-bikes. Compared to conventional cyclists, e-bike riders were found to be especially at higher risk of safety critical situations at intersections (Dozza et al. 2016), e.g., when car drivers did not did not yield right-of-way to an e-bike (Petzoldt et al. 2017a; Schleinitz et al. 2014), presumably because they underestimated the e-bike's speed. A unique appearance alone might not be enough to fully eradicate this type of conflict.

It should be acknowledged that the rather artificial task and setting certainly limits the external validity of the findings. The usage of video footage, as well as requiring participants to simply press a button to indicate behavioural intent is not fully comparable to a turning manoeuvre in real traffic. A confirmation of our findings in a more realistic setting, e.g. on a test track, with actual cyclists approaching (Petzoldt et al., 2017b), or at least in a driving simulator with virtual cyclists, is required to allow for more definite statements on the potential effects of measures to improve e-bikes' safety. Also, the fact that the videos were of variable length meant that the initial gap size differed between speed levels (from 10.3 s at 35 km/h to 24.0 s at 15 km/h), which, at least in theory, might have constrained participants' indication of acceptable gaps.

Furthermore, from a practical point of view, to achieve a unique appearance, a re-design of the e-bike would be preferable to a "re-design" of the rider. Any potential measure designed to improve the safety of e-bike riders (and other road users who interact with them) should be independent of the motivation (or the memory) of the rider. Our rather simple experimental implementation of a potential measure was only a crude first attempt, with a number of potential flaws that would need to be addressed for a proper solution. For example, one potential side effect of our specific implementation might be the fact that, while it would result in e-bike riders being more visible in general, potentially improving their safety, it also carries the potential for negative effects on the safety of other bicyclists (who would be less conspicuous in comparison). Furthermore, while our participants were not naïve with regard to the meaning of the orange helmet, we cannot completely rule out the idea that, on a subconscious level, the selected colour might have been associated with "risk", and could somehow have influenced participants' judgment. Still, with all due acknowledgement of the investigation's limitations, the central finding remains valid: There is some potential, with the help of rather simple means, to modify road users' gap acceptance behaviour, so that e-bike riders might not simply have to wait for other road users to get used to them to finally be safe on the road.

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TABLES AND FIGURES

Table 1. Summary of ANOVA results for the gap size in seconds. Significant effects in boldface (*N* = 49).

	df	*F*	*p*	η^2_p
speed *	4	129.67	**<.001**	.73
bicycle type	1	0.06	.810	.00
helmet colour	1	21.67	**<.001**	.31
speed x bicycle type *	4	1.58	.199	.03
speed x helmet colour *	4	3.05	**.040**	.06
bicycle type x helmet colour	1	0.16	.689	.00
speed x bicycle type x helmet colour *	4	1.88	.141	.04

* Greenhouse Geisser correction

Figure 1. Screenshots from 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), rider wearing orange helmet (supposed e-bike).

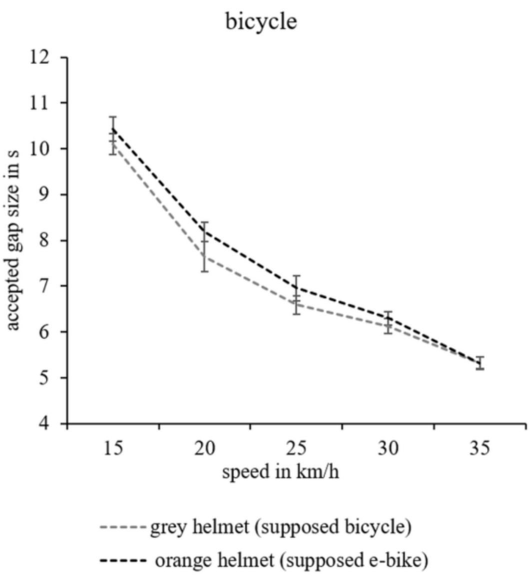

Figure 2. Mean accepted gap size in seconds for the different speed levels dependent on helmet colour for the actual bicycle. Error bars represent 95% confidence intervals (*N* = 49).

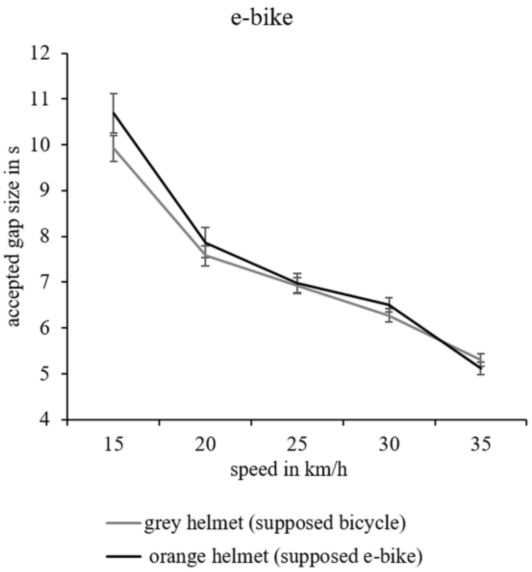

Figure 3. Mean accepted gap size in seconds for the different speed levels dependent on helmet colour for the actual e-bike. Error bars represent 95% confidence intervals (*N* = 49).

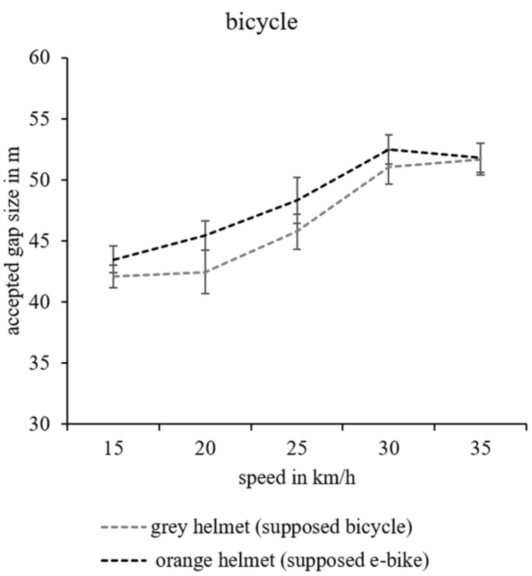

Figure 4. Mean accepted gap size in meters for the different speed levels dependent on helmet colour for the actual bicycle. Error bars represent 95% confidence intervals (*N* = 49).

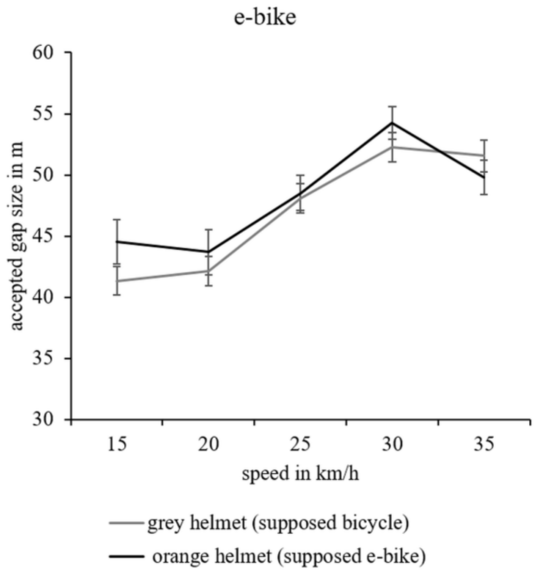

Figure 5. Mean accepted gap size in meters for the different speed levels dependent on helmet colour for the actual e-bike. Error bars represent 95% confidence intervals (N = 49).

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APPENDIX

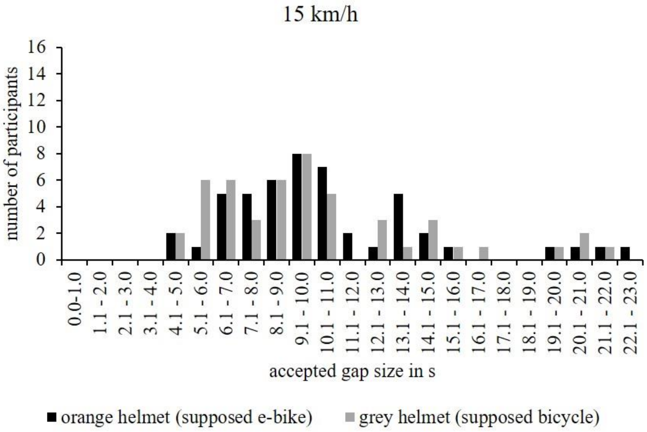

Figure A1. Distribution of responses for 15 km/h and the different helmet colours (*N* = 49).

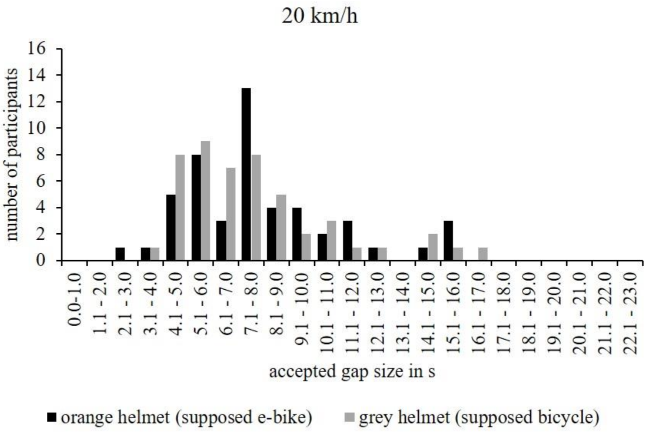

Figure A2. Distribution of responses for 20 km/h and the different helmet colours (*N* = 49).

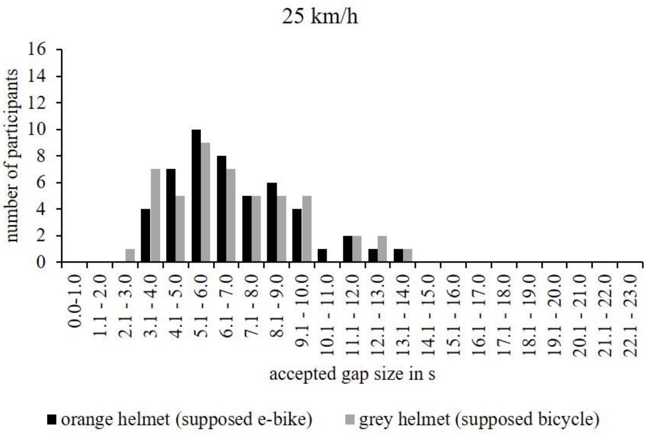

Figure A3. Distribution of responses for 25 km/h and the different helmet colours (*N* = 49).

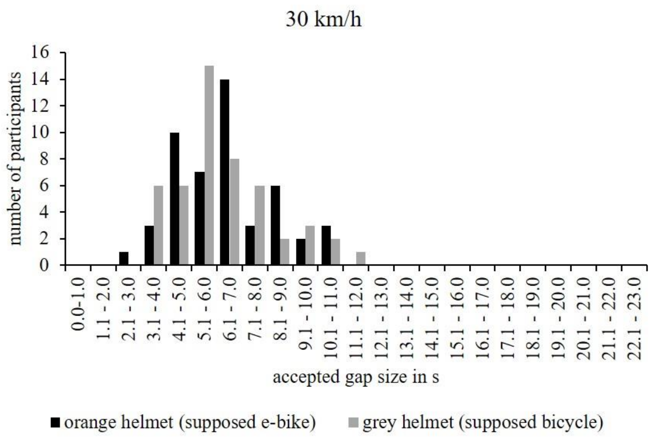

Figure A4. Distribution of responses for 30 km/h and the different helmet colours (*N* = 49).

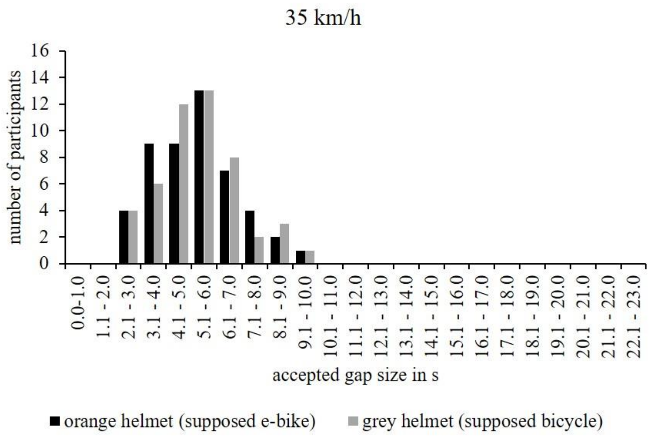

Figure A5. Distribution of responses for 35 km/h and the different helmet colours (*N* = 49).