Cite as: Schleinitz, K., Petzoldt, T., & Gehlert, T. (2018). Risk compensation? – The relationship between helmet use and cycling speed under naturalistic conditions. Journal of Safety Research, 67, 165-171. doi:10.1016/j.jsr.2018.10.006

Risk compensation? – The relationship between helmet use and cycling speed under naturalistic conditions

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ABSTRACT

Introduction: An argument against mandatory helmet use is based on the idea of risk compensation, which means that cyclists might ride faster when wearing a helmet (Lardelli-Claret et al., 2003). However, questionnaire and experimental studies were unable to find evidence for this assumption (Fyhri et al., 2012; Fyhri & Philipps, 2013). Simultaneously, other factors with a potential role in helmet use and cycling speed, such as trip length and rider characteristics have been neglected in such considerations. The goal of the analysis presented in this paper was therefore to investigate the relationship between helmet use and cycling speed under naturalistic conditions while taking characteristics of cyclists and bicycles into account.

Method: As part of a naturalistic cycling study, we equipped the bicycles of conventional and e-bike riders with data acquisition systems to record speed and trip distance. It included two cameras (one for the face of the participant, another one for the forward scenery). For the analysis presented in this paper, we used the data of 76 participants (28 conventional bicycles, 48 e-bikes).

Results: In total, participants used their helmet for 56% of all trips. Helmets were used more frequently for longer trips. A linear mixed model, in which trip length, helmet use, bicycle type, age and gender were used as predictors showed that helmet use did not play a significant role for cycling speed. Instead, all other factors that were analysed, with the exception of gender, had a significant relationship to cycling speed.

Discussion: The assumption of risk compensation as a result of the use of a helmet could not be confirmed. Instead, the findings seem to support the suggestion that cyclists who undertake trips at potentially higher speed levels are aware of their increased risk, and actively try to reduce it through the use of a helmet.

Keywords: naturalistic cycling study, trip length, electric bicycles, bicycle helmet, age

INTRODUCTION

Habitual helmet use is still the exception, rather than the rule, among cyclists. In 2015, only 18% of observed German cyclists wore a helmet (von Below, 2016)**,** a proportion that constitutes only a slight increase compared to previous years (von Below, 2013; Wandtner, 2014, 2015). At the same time, available research unambiguously points to the fact that cycling helmets can reduce crash severity (Olivier & Creighton, 2017; Orsi, Ferraro, Montomoli, Otte, & Morandi, 2014; Rivara, Thompson, Patterson, & Thompson, 1998). Amoros, Chiron, Martin, Thelot and Laumon (2012) found that helmets generally reduce the risk of head injuries, and in particular protect against the most serious of such injuries. Data from the US show a decrease in the number of fatalities and severe head injuries among cyclists after the introduction of mandatory helmet use in the city of Seattle (Kett, Rivara, Gomez, Kirk, & Yantsides, 2016). Nevertheless, making helmet use mandatory through corresponding legislation is highly controversial, since the positive effects of helmets (such as the reduction of head injuries in the event of a crash) could be offset by additional negative effects. It has been argued that bicycle helmet laws might act as a deterrent to potential cyclists, reduce the amount of cycling and as a consequence eliminate the positive effects on health (Sieg, 2016). In a frequently cited (however heavily criticised – Olivier & Walter, 2013) study, Walker (2007) found that drivers might modify their passing distance dependent on a cyclist's usage of a helmet, with closer passing of those who wore helmets.

In addition, it has also been argued that cyclists themselves might change their cycling behaviour as a result of wearing a helmet. More precisely, it has been suggested that, based on the idea of risk compensation, cyclists might adapt their behaviour in accordance to the perceived risk in a given situation, a risk that would be perceived as being reduced because of wearing a helmet (Adams & Hillman, 2001; Hagel & Barry Pless, 2006). As a consequence, cyclists who wear a helmet might, e.g., cycle faster, and hence objectively increase their risk of being involved in a crash (Lardelli-Claret et al., 2003). Evidence for this suggestion, however, is hard to find. In Norway, about 1,500 cyclists were asked about helmet use, risk perception and cycling at high speed (Fyhri, Bjornskau, & Backer-Grondahl, 2012). The findings indicate that the intention / expectation of riding fast is the reason for helmet use, and not the other way around. According to the authors, faster cyclists appear to be aware of their increased risk, and actively try to reduce it through helmet use. At the same time, the participants' self-reported information provided no evidence for a relationship between helmet use and crash involvement. Similarly, experimental studies have, so far, failed to provide evidence for cyclist risk compensation. Fyhri and Phillips (2013) manipulated helmet use among routine helmet users as well as cyclists who reported to never wear a helmet. In one of the experimental blocks, participants were required to wear a helmet, in a second block, they rode without one. The results show that routine helmet users cycled slower when not wearing a helmet compared to the condition in which they wore a helmet (i.e., they slowed down when their usual protection was removed). However, there was no comparable effect for non-helmet users, i.e., they did not increase their speed once they wore a helmet. The authors concluded that requiring riders to use a helmet would not lead to increased speed.

One major criticism of such experimental approaches is the issue of validity. It might be argued that any long-term behavioural adaptation to a cycling helmet cannot be induced in or inferred from an experiment. Likewise, the role of other relevant factors for both helmet use and speed is not fully clear, and often cannot be tested in an experimental environment. For example, it is known that helmet use is somewhat correlated with trip length. In interviews and questionnaires cyclists stated that they do not use a helmet for short trips (Kakefuda, Stallones, & Gibbs, 2009; Lajunen, 2016; Teschke et al., 2012). Lajunen (2016) claimed that an anticipated short trip length is a central barrier for helmet use. At the same time, trip length is correlated with trip purpose (e.g., minor errands vs. commute vs. recreational weekend ride), and, as a consequence, not independent of cycling context (e.g., type of road, frequency of intersections, presence of other road users), factors that all might impact on cycling speed. It is also known that the willingness to use a helmet is related to the gender and age of the cyclist (Fischer et al., 2012; Ritter & Vance, 2011), two factors that are associated with speed and trip length as well. Women, on average, ride at slower speed than men, and their trips are shorter too (Petzoldt, Schleinitz, Heilmann, & Gehlert, 2017;

Scaramuzza, Uhr, & Niemann, 2015). Similarly, older riders are, on average, slower than younger riders, and complete shorter trips as well (Scaramuzza et al., 2015; Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2017; Vlakveld et al., 2015). Finally, the increased popularity of electric bicycles is a factor to consider, given that several studies have shown that the mean speeds as well as trip distances of e-bike riders differ considerably from those of users of conventional bicycles (Jellinek, Hildebrandt, Pfaffenbichler, & Lemmerer, 2013; Schleinitz et al., 2017).

To address the described issues, long-term observations of bicyclists under naturalistic conditions are required. Such naturalistic cycling studies (Dozza, Piccinini, & Werneke, 2016; Johnson, Charlton, Oxley, & Newstead, 2010) help to paint a realistic picture of cyclists' behaviour, including aspects such as helmet use, speed or trip length, and allow for the investigation of the effect of each of these factors, as well as the interactions between them. The goal of this study was therefore to make use of such data, and assess the relationship between helmet use and cycling speed under naturalistic conditions while taking characteristics of the riders and bicycles into account. The analysis presented is based on data collected in a naturalistic cycling study, in which more than 2,300 hours of cycling had been recorded (Schleinitz et al., 2014).

METHOD

Participants

Participants were recruited through flyers in cycling shops and ads in newspapers. We selected our participants out of about 180 applicants based on criteria such as gender, age, what type of bicycle they own, or how often they ride. The participants were supposed to ride either a conventional bicycle or one of two e-bike types (pedelec and S-pedelec[2]), and cycle at least three times a week only in Chemnitz or the

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[2] In Germany, we distinguish between pedelecs and S-pedelecs. Pedelecs support pedalling up to 25 km/h (250W), are legally treated as conventional bicycles and constitute 99% of e-bikes sold (Zweirad-Industrie-Verband, 2017). S-pedelecs support pedalling up to 45 km/h (500W), and are legally categorised as powered two wheelers, i.e. the rider needs to be in possession of a moped driving licence, and is required to wear a helmet (Lawinger & Bastian, 2013). Similar categorisations (often with consequences for licensing, insurance etc.) exist in most European countries (Jellinek et al., 2013).

surrounding areas. In addition, the e-bike riders were required to have at least three months of experience with their bicycle. In total, 90 participants in three age brackets (≤ 40 years; 41 - 64 years; ≥ 65 years) were selected (31 cyclists, 49 pedelec riders, 10 S-pedelec riders). The S-pedelec group was not included in the analysis reported in this paper, as S-pedelec riders have to use their helmets mandatory. Their motives to use a helmet are very different from those of conventional cyclists and pedelec riders. Out of the remaining 80 datasets, we had to remove the data of four participants because of technical issues (no face video available, i.e. no information on helmet use), which resulted in a final dataset of 76 participants (32 female, 44 male). Twenty-eight of them rode a conventional bicycle (11 female, 17 male) and 48 a pedelec (21 female, 27 male). The cyclists were, on average, 53 years old (*SD* = 17.2, *Min* = 16, *Max* = 75), the e-bike riders 54 years (*SD* = 16.6, *Min* = 24, *Max* = 74). Table 1 shows the distribution of participants across age groups and bicycle types. According to the screening questionnaire, participants used their bicycle on 5 days a week on average. All participants received monetary compensation of 100€ for their cooperation.

Table 1. *Number of participants per age group and bicycle type (N = 76).*

Age groups	Cyclists			Pedelec riders		
	N	*M age*	*SD age*	*N*	*M age*	*SD age*
≤ 40 years	8	30.8	7.1	15	33.3	6.6
41 - 64 years	9	52.4	8.5	14	54.1	7.2
≥ 65 years	11	69.5	3.2	19	70.4	3.2
Total	28	52.9	17.2	48	54.0	16.6

N = Number of participants, *M*= mean, *SD* = standard deviation.

Data acquisition system

The participants' bicycles / pedelecs were equipped with a data acquisition system (DAS), which included wheel sensors (2 Hz) to record speed and distance, as well as two cameras (Type ACME FlyCamOne eco

V2), a GPS sensor and a battery. One camera recorded the face of the participant (see Figure 1) and the other one the forward scenery (both cameras: 30 Hz with a resolution of 720x480 pixels). The DAS was mounted on the handlebar of the bicycle, and could be activated with the help of a single flip switch.

Figure 1. Example of video footage.

Procedure

During the installation of the DAS, the participants filled in the pre-study questionnaire, which asked about aspects such as their cycling behaviour or the purpose of their usual cycling trips. For data acquisition, participants were instructed to use their bicycle or pedelec as they normally would, which also included the (non)usage of a helmet. They were asked to record each trip they made. For each participant, data was collected over a period of four weeks. During the period of data acquisition, trained technicians carried out maintenance procedures (DAS repairs and exchange of storage media) whenever needed. After four weeks, the DAS was dismounted and the participants filled in the post-study questionnaire, which included questions about the handling of the DAS (e.g., if they had always activated the system and if not, why). The answers imply that only a few trips might have been lost. The reasons usually provided for not activating the system were “forgotten” or “battery dead”, which imply that there would be no systematic pattern in these lost trips.

Data analysis

The videos of the riders' face were used to address the question of helmet use. For all videos, the start and the end of a trip were reviewed with respect to the rider's (non)usage of a helmet during this trip (see Figure 1). No case was identified in which the rider removed the helmet during the trip (i.e., no difference in usage between start and end), so that all trips could be clearly coded as either "with helmet" or "without helmet". This information was then linked to information on trip length, cycling speed and demographic data in a database. Cycling speed was analysed excluding all situations in which the bicycle was stationary (speed = 0 km/h). Nonparametric tests were used to test for statistical significance, since data was not normally distributed.

Data on cycling speed was analysed using a linear mixed effect model (LMM). In the model, trip length, age (as continuous variables) and helmet use (codes: 0 = no helmet, 1 = helmet), gender (0 = female, 1 = male), and bicycle type (0 = bicycle, 1 = pedelec) as dichotomous variables as well as interactions between helmet use and the other factors were included. Cycling speed was the dependent variable[3]. To control for participants' influence, a LMM with a random effect for participants and fixed effects for all other predictors was specified using package "lme4" (Bates, Maechler, Bolker & Walker, 2015) in R 3.5.0 (R Core Team, 2018). To further analyse significant interactions (two were found, which both happened to include helmet use as one of the factors), they were broken down by calculating separate LMM for trips without helmet and trips with helmet (see Field, Miles, & Field, 2012). The model included the same predictors as the main model with the exception of helmet use. For the model fit, pseudo R^2_m and pseudo R^2_c were specified. Pseudo R^2_m describes the variance explained by fixed factors and pseudo R^2_c represent the variance explained by the whole model including random factors (intercept).

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[3] In the description of the results of such models, phrases like "significant effect of a on b" are commonly used (and also are used in the results section of this article). Such a phrasing is supposed to point out effect in a statistical sense, however should not be interpreted as an implication of actual causality.

RESULTS

In total, the participants recorded nearly 12,700 kilometres of cycling. The data of 3,416 trips could be included in the analysis. The first part of the reported analysis provides mostly descriptive results on helmet use and trip length, and how they relate to the participant factors of age, gender and bicycle type. In the second part, the results of the main analysis on cycling speed are reported, in which helmet use, trip length, age, gender, and bicycle type are all treated as (potentially) relevant influencing factors.

Helmet use

Among the analysed trips, we found 1,902 trips with helmet and 1,514 trips without helmet, which corresponds to a helmet usage rate of 56%. Figure 2 shows the usage rate for each participating rider. Around 35% of our conventional cyclists more or less never wore a helmet, while this was the case for only 20% of the pedelec riders. About half of the conventional cyclists used a helmet occasionally. Among the pedelec riders, the share was somewhat lower with about 37%. Only about 15% of the cyclists wore a helmet on almost every ride, compared to nearly half of the pedelec riders. In general, pedelec riders used a helmet more often (66%) than riders of conventional bicycles (42%), a difference that was found to be statistically significant (*U* = 445.5, *p* = .013, data analysed on subject level).

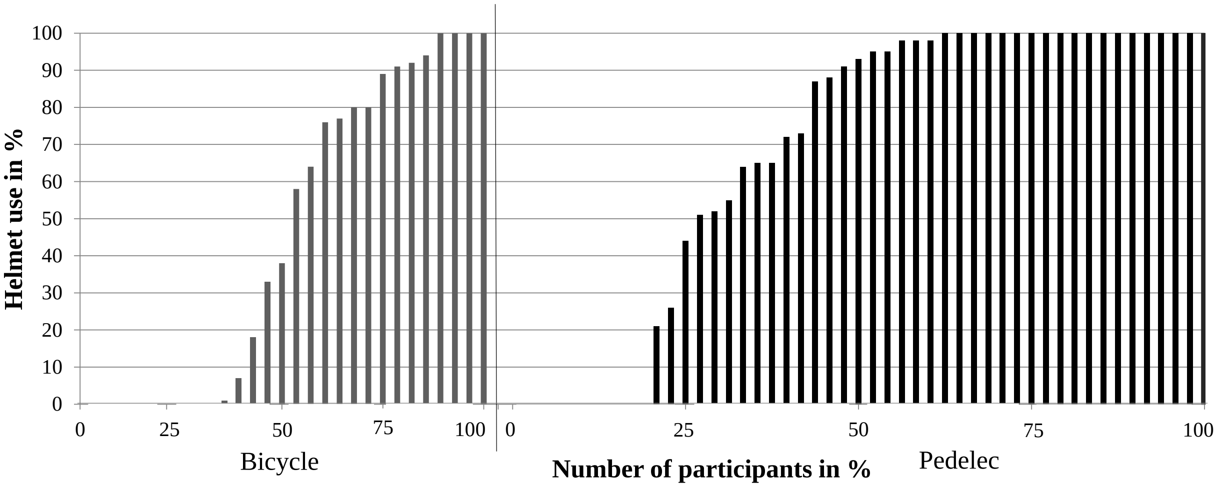

Figure 2. Percentage of trips with helmet (in %) separated by type of bike. Each bar represents one rider (*N* = 76).

Although our participants 65 years and older showed a slightly higher helmet usage rate (61%) than the participants 41 to 64 years (52%) and the participants 40 years and younger (52%), there was no statistically relevant difference between the three age groups (*H* = 0.260; *p* = .878). There was no difference in helmet use between male and female participants (both 58%, *U* = 708.0, *p* = .966).

Trip Length

Mean trip length across all trips was 3.7 km (*Mdn* = 2.4 km, *SD* = 3.8 km). Most of the trips were between 1 and 5 km long (see Figure 3), while only a small portion was longer than 15 km.

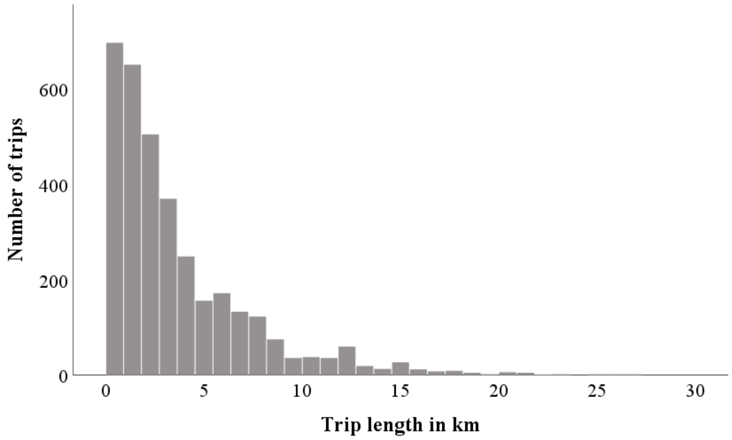

Figure 3. Histogram of trip length (an outlier trip of 40.9 km length is not depicted, *n = 3,416*).

Overall, trips in which participants wore a helmet were longer than trips without helmet see Table 2). A visualisation of this relationship (for occasional helmet users) can be found in the Appendix. In addition, we found that, on average, the trips of pedelec riders were longer compared to the trips of conventional cyclists. With regard to age, the longest trips were completed by riders between 41 and 64 years of age, whereas the younger riders completed the shortest distances. Likewise, we found a small difference with regard to gender, as trips completed by male riders appeared to be slightly longer than those of female cyclists.

Table 2. *Descriptive results for the influencing factors on trip length in km (N = 76, 3,471 trips).*

		N	*M*	*SD*	*95% CI*
Helmet use	with helmet	1903	4.5	4.4	4.3, 4.7
	without helmet	1514	2.7	2.6	2.6, 2.8
Bicycle type	bicycle	1498	3.2	3.6	3.0, 3.4
	pedelec	1919	4.1	3.9	3.9, 4.3
Age group	≤ 40 years	1042	3.3	3.1	3.2, 3.5
	41-64 years	912	4.0	4.1	3.7, 4.2
	≥ 65 years	1463	3.8	4.0	3.6, 4.0
Gender	male	1906	4.1	4.2	4.0, 4.3
	female	1511	3.2	3.1	3.0, 3.3

Speed

Similar to the descriptive analysis of trip length, Table 3 gives an overview of mean speed for the different factor levels of helmet use and bicycle type, as well as age and gender of the rider. Speed was slightly higher in trips in which participants wore a helmet compared to trips without helmet. In addition, we found that trips by pedelec were slightly faster than trips with a conventional bicycle. Mean speed in trips completed by older riders was lower compared to the other two age groups. In addition, trips by female riders were slower than those of male ones.

Table 3. *Descriptive results for the influencing factors on speed in km/h (excl. 0 km/h, N = 76, 3,471 trips).*

		N	*M*	*SD*	*95% CI*
Helmet use	with helmet	1903	16.1	5.0	15.9, 16.3
	without helmet	1514	15.0	4.6	14.8, 15.3
Bicycle type	bicycle	1498	15.2	4.2	15.0, 15.4
	pedelec	1919	15.9	5.2	15.7, 16.2
Age group	≤ 40 years	1042	18.3	5.6	17.9, 18.6
	41-64 years	912	15.6	5.8	15.3, 15.9
	≥ 65 years	1463	13.7	3.4	13.6, 13.9
Gender	male	1906	16.6	5.2	16.4, 16.9
	female	1511	14.3	3.9	14.1, 14.5

Figure 4 shows the correlation between trip length and mean cycling speed for trips by bicycle and pedelec. For cyclists as well as pedelec riders, longer trips went with higher mean speed, which is also reflected in significant correlations between the two variables ($r_{\text{bicycle}} = .301$, $p < .001$; $r_{\text{pedelec}} = .483$, $p < .001$). What is visible from the figure is that up to a certain trip length, the relationship between trip length and mean speed is nearly linear, while beyond that point, increases in mean speed are minimal. The patterns for trips by cyclists and pedelec riders are highly similar, except that certain levels of mean speed were only reached by pedelec riders.

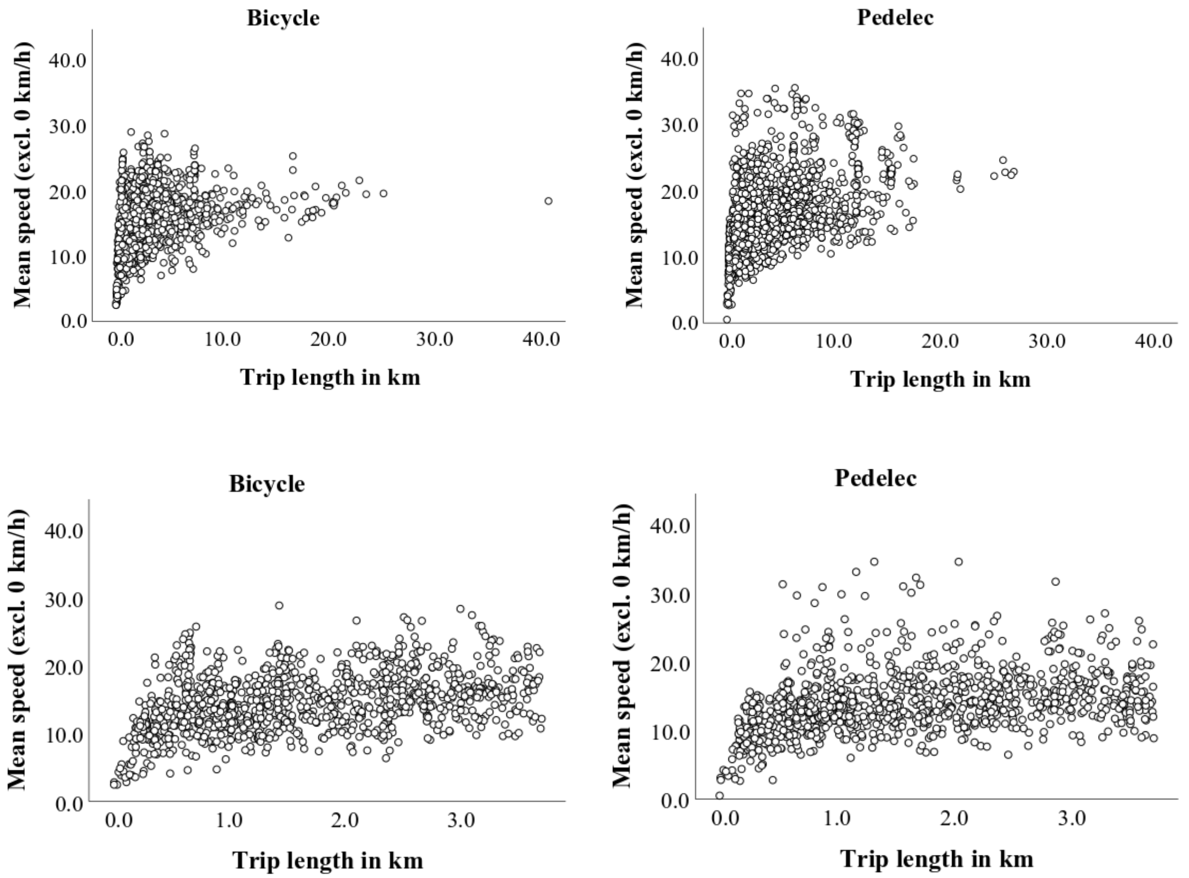

Figure 4. Top: correlation between mean speed per trip (excl. 0 km/h) and trip length for all trips by bicycle (left, n = 1,498) and pedelec (right, n = 1,919); bottom: the same correlation plotted only for trips by bicycle (left, n = 1,095) and pedelec (right, n = 1,148) shorter than the mean trip length (3.7 km).

To take the effects of all the recorded factors on speed into account, a LMM was applied to investigate the relationship between helmet use, trip length, age (as continuous variable), gender, and bicycle type as predictors and cycling speed as the predicted variable (see Table 4). The fixed effects of the LMM explain 39.3% of the variance (pseudo R^2_m = .393), whereas the whole model inclusive random effect explains a considerable larger amount of variance with 66.7% (pseudo R^2_c = .667). The model shows a significant age effect on cycling speed, with older riders cycling slower than younger ones. Trip length was found to be a significant predictor as well, with longer trips being accompanied by higher speed. Not surprisingly, also bicycle type had a significant effect, with pedelec riders being faster than riders of conventional bicycles. Helmet use and gender, however, had no statistically relevant predictive value for mean trip speed.

In addition to the described main effects, we found two significant interactions (helmet use * trip length and helmet use *gender). These interactions were broken down by conducting two separate LMM, one for trips with helmet und one for trips without helmet. The analysis for trip length and helmet use showed that, while trip length predicted speed for both trips with and without helmet (higher speed with longer trips), the effect was more pronounced for trips without helmet (with helmet: $b = 0.383$, $t(1{,}901.2) = 21.04$, $p < .001$; without helmet: $b = 0.604$, $t(1{,}494.6) = 19.07$, $p < .001$). For the significant interaction of helmet and gender, the two separate models revealed that gender had only predictive value when trips were completed without helmet (men without helmet rode faster as women; $b = 2.129$, $t(57.0) = 3.00$, $p = .004$), whereas there was no such effect for trips with helmet ($b = 1.105$, $t(44.3) = 1.41$, $p = .165$).

Table 4. *Results of the linear mixed model for age, trip length, gender, bicycle type and helmet use with a random effect for participants (intercept, N = 76, 3,417 trips).*

Predictor	***b***	***SE b***	**CI 95%**	***p***
Intercept	18.740	1.202	16.440 – 21.197	< .001
Age	-0.136	0.019	-0.175 – -0.098	< .001
Trip length	0.590	0.031	0.528 – 0.651	< .001
Gender	1.294	0.659	0.019 – 2.588	.052
Bicycle type	1.972	0.677	0.609 – 3.329	.004
Helmet use	1.240	0.688	-0.092 – 2.597	.072
Helmet * age	-0.006	0.011	-0.027 – 0.016	.541
Helmet * trip length	-0.201	0.035	-0.272 – -0.132	< .001
Helmet * gender	1.048	0.377	0.297 – 1.766	.006
Helmet * bicycle type	-0.643	0.378	-1.395 – 0.073	.088

DISCUSSION

The main goal of this study was to investigate the relationship between helmet use and cycling speed under naturalistic conditions while taking characteristics of cyclists and bicycle as well as trip length into account. The analysis of the data did not find a significant relationship between helmet use and cycling speed. Based on this result, the assumption that helmet use would result in some form of risk compensation could not be supported, which is in line with findings of Fyhri and Phillips (2013). Instead, rider related factors, such as rider's age or bicycle type were found to be significant predictors of cycling speed (while gender was not). Corresponding to results of other studies, older riders travelled slower than younger ones (Jellinek et al., 2013) and pedelec riders travelled faster than cyclists (Huertas-Leyva, Dozza & Baldazini, 2018; Vlakveld et al., 2015).

Most instructive, however, was the role of trip length in our analyses. In line with previous findings, there was a clear relationship between trip length and helmet use (Kakefuda et al., 2009), as, on average, cycling trips for which riders wore a helmet were longer compared to those without. At the same time, we found a clear correlation between trip length and cycling speed, as longer trips went with higher speeds. Confirming this impression, the LMM showed that trip length was a significant predictor of cycling speed. Altogether, this strongly suggests that investigations of helmet use and cycling speed in the field have to take trip length into consideration, as it is likely that any correlation between helmet use and cycling speed is actually the result of a relationship between trip length and speed, with helmet use only being a side effect.

It should be acknowledged, however, that the significant role of trip length itself might actually be the result of a variety of underlying factors. For example, trip length must be assumed to be highly correlated with trip purpose, which, in turn, has an impact on the environmental characteristics under which such a trip takes place. Cyclists are more likely to use a helmet for longer sports and recreational trips instead for commuting or trips for errands (Jürgensohn, Schwarz, Kretschmer, Heß, & Platho, 2017; Teschke et al., 2012). During recreational trips, cyclists are more likely to cover the surrounding areas of the cities, where they can travel with higher speeds, both because of specific infrastructure characteristics (e.g. fewer intersections) and reduced surrounding traffic (which has been found to slow cyclists down, Bernardi & Rupi, 2015). Consequently, the identification of trip purposes, and the detailed annotation of the cycling environment during the trip might proof valuable for answering more specific research questions, and is something that should be pursued in future studies. A time series annotation of characteristics of the surroundings during the ride, such as road type, weather conditions, road surface quality, surrounding traffic etc. can help clarify speed choice on a micro level (however, is beyond the scope of the analysis reported in this paper). Trip purpose might, to some degree, also be inferred from the review of video material (with a considerable degree of error to be expected), but will ultimately remain unknown to the outside observer. Trip diaries that require riders to report aspects such as the reason for a certain trip can be a useful addition to such an investigation, if a sufficient level of data quality can be assured. However, it should be taken care that this requirement does not interfere too much with the general idea of the naturalistic approach, which is to observe unobtrusively.

The principal limitations of the naturalistic approach should be acknowledged as well. An issue that is especially critical in naturalistic cycling (compared to naturalistic driving) is the role of the geographic location of the study. Even within one and the same country, cycling behaviour (especially speed, distances) might differ considerably dependent on whether the surrounding are, e.g., rather flat or quite mountainous, which somewhat limits the generalisability of the findings. Furthermore, even within one and the same environment, control over geographical characteristics, e.g., gradient of the road, or environmental conditions, e.g., traffic density or weather, is practically impossible, although such factors undeniably could impact on rider's speed independent from the factors considered in this analysis. Even though we made an effort to mitigate these influences through the large number of trips and the considerable number of participants that went into this analysis, they cannot be completely avoided. This lack of control over potential confounding variables makes inferences regarding actual causality impossible. While the naturalistic approach can absolutely help generate reasonable hypotheses that might be tested further under more controlled conditions, it should again be pointed out that the results of our investigation merely show statistical relationships, and it is not intended to imply that any of the predictor variables is actually the root cause for any measured variation in cycling speed.

It also should be noted that our participants' helmet usage rate of nearly 60% was clearly higher than what has been reported from other observations in Germany (von Below, 2016; Wandtner, 2015). One potential explanation might be found in the subject sample for this investigation. It can be assumed that the reliance on volunteer participants has resulted in a rather safety conscious sample, as a high cycling frequency and an interest in safety related issues might certainly be prevalent in those willing to participate. This might also explain why, contrary to previous investigations of German cyclists (Ritter & Vance, 2011; von Below, 2016), we did not find differences in helmet usage rates between age groups or male and female riders (although it should be pointed out that in general, reports on the effects of age and gender on helmet use are inconsistent, (see, e.g. Fischer et al., 2012; Fyhri et al., 2012; Lajunen, 2016).

CONCLUSION

This study has used naturalistic cycling data to investigate the relationship between helmet use and cycling speed while taking characteristics of cyclists and bicycle as well as trip length into account. It had been suggested previously that helmet use would result in some form of risk compensation that might manifest itself in an increase of cycling speed (Messiah, Constant, Contrand, Felonneau, & Lagarde, 2012; critisised by Olivier, Esmaeilikia, & Grzebieta, 2018), a suggestion that was not supported by our results. Given that the potential for behavioural adaptation on behalf of the cyclist is one argument that has repeatedly been provided by opponents of mandatory helmet use (see Olivier et al., 2018; Robinson, 2006, 2007), this finding is highly relevant. While the results are far from proof that there would be no behavioural adaptation at all, they at least clarify that it is unlikely that riders would simply increase speed once they wear a helmet. Insofar, the results might help re-focus the search for indicators of behavioural adaptation. While quite a few authors argue (convincingly) about behavioural adaptation in an abstract form, basing their arguments mainly on theoretical considerations (e.g., Adams & Hillman), the actual behavioural change that is supposed to occur remains mostly in the dark. Our data provide some empirical indication that a change in riding speed is probably not what we should be looking for. So, maybe, it is more worthwhile to instead look into other aspects of cycling behaviour, such as risky manoeuvres (which, of course, requires a good definition of “risky”, which might be rather difficult) or violations, to uncover risk compensation.

It should of course be noted that even a general absence of behavioural adaptation on behalf of the cyclists would not mean that a requirement to wear a helmet when cycling would be without negative consequences. The issue of behavioural adaptation on behalf of the drivers of motorised vehicles, just as the potentially deterring impact of mandatory helmet use, are still powerful (and reasonable) arguments. Instead, our results should be viewed only as a minor, but relevant contribution to the discussion, which, to a considerable degree, has been based on assumptions which not always have been grounded in empirical data.

ACKNOWLEDGMENTS

The research presented in this paper was funded by German Insurers Accident Research (UDV). We thank André Körner for his help with R statistics.

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APPENDIX

To illustrate the relationship between helmet use and trip length, we attempted to map and visualise our participants' individual trips made with and without helmet (Figure 5). We limited this visualisation to "occasional helmet users", which were observed riding both with and without helmet in the video material. We included all of those for which we had a sufficient number (min. five) of usable GPS tracks (*n* = 18). The visualisation was carried out using R (R Core Team, 2018) in combination with Open Street Maps (openstreetmap.org). Each trip was mapped on a map of the city of Chemnitz and the surrounding areas (where the study took place). Trips made wearing a helmet (left, in blue) are visibly longer than the trips without helmet (right, in red). They also more often seem to include the surroundings of the city (centred in both maps) as compared to trips without helmet, which seem to concentrate mostly inside the city (note, however, the overall different numbers of cases with and without helmet).

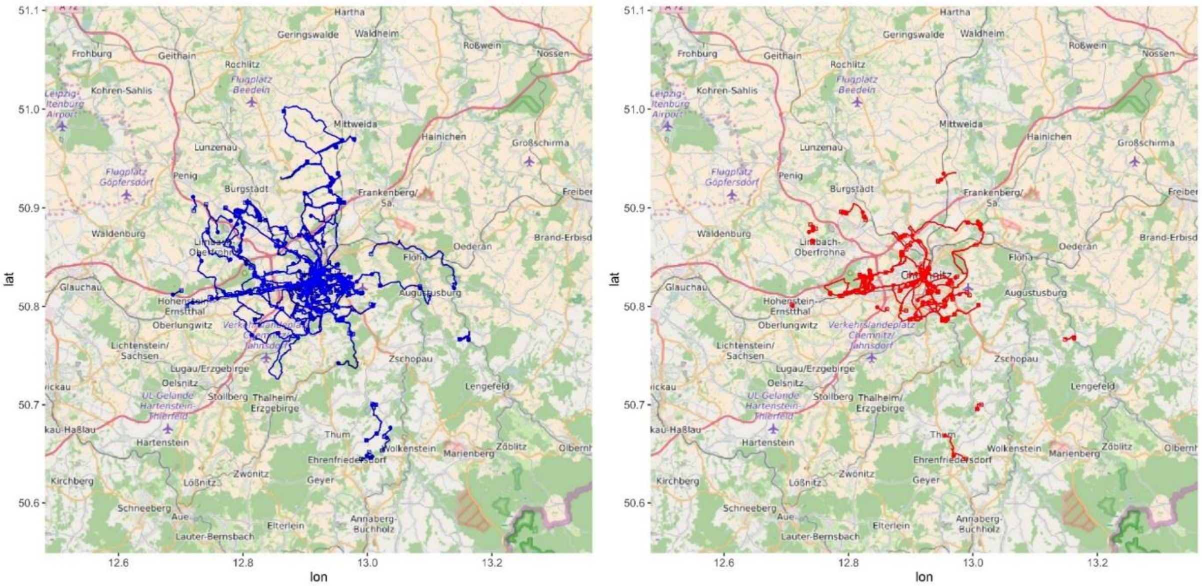

Figure 5. Illustration of trips of occasional helmet users. Left: trips with helmet in blue (*n* = 399); right: trips without helmet in red (*n* = 140), Source: Open Street Maps Maps (openstreetmap.org).