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Impact of electrically assisted bicycles on physical activity and traffic accident risk: a prospective observational study

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ABSTRACT

Background Electrically assisted bicycles (e-bikes) have become increasingly popular and may facilitate active commuting and recreational cycling.

Objective To evaluate the physical activity levels and usage characteristics of e-bikers and conventional cyclists under real-world conditions.

Methods We conducted a prospective observational study in Germany to examine the effects of e-biking compared with conventional cycling on reaching the World Health Organization (WHO) target for physical activity—at least 150 min of moderate-to-vigorous physical activity (MVPA) per week. Study participants (1250 e-bikers and 629 conventional bike users) were equipped with activity trackers to assess the time, distance and heart rate during cycling over four consecutive weeks. Questionnaires were used to assess any traffic accidents incurred over 12 months.

Results The proportion of participants reaching 150 min of MVPA per week was higher for conventional bike users than for e-bike users (35.0% vs 22.4%, p<0.001). In a multiple regression model, the odds of reaching the physical activity target were lower for e-biking than for conventional biking (OR=0.56; 95% CI 0.43 to 0.72) with age, sex, comorbidities and bike usage patterns as confounding factors. No significant differences were observed between bike groups for traffic accidents, yet when controlled for cycling time and frequency of cycling e-bikers had a higher risk of a traffic accident (OR=1.63; 95% CI 1.02 to 2.58).

Conclusion E-bikes are associated with a lower probability of reaching WHO targets for MVPA due to reduced duration and a reduced cardiovascular effort during riding. However, e-bikes might facilitate active transportation, particularly in older individuals or those with pre-existing conditions.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Electrically assisted bicycles may help to increase physical activity, yet data on usage in everyday life and the intensity of e-biking are limited and inconclusive.

WHAT THIS STUDY ADDS

⇒ E-bikers generally cycled less frequently, for a shorter overall duration and at lower intensities than conventional bike users.

⇒ E-bikers used their bikes mainly to alleviate physical strain during cycling and promote health. They were more likely than conventional bike users to replace their cars with e-bikes for different journeys.

⇒ The risk for road traffic accidents and near-accidents was similar between bike groups.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ In general, the expected health effects of cycling might be higher for bicycle users than for e-bike users. Yet, e-bikes might enable regular cycling for individuals who are limited by age- or illness-associated constrictions and would not otherwise consider conventional cycling.

INTRODUCTION

Tackling climate change is a major public health issue of the present day. In this context, facilitating electromobility has become a key political objective.[1] Bicycles that provide electric assistance only when the rider pedals (e-bikes) have become increasingly popular in recent years. Around 3.4 million e-bikes were sold in the European Union in 2019, compared with only 98 000 in 2006.[2] This number is expected to increase further to 62 million by 2030.[1] A similarly rapid increase throughout Europe is also anticipated in Asia and the USA.[3 4]

E-bikes and other forms of electromobility are connected with the hope of partly replacing CO_2-emitting vehicles and contributing to reduced car traffic and congestion.[5] In addition to this potential ecological and infrastructural impact, e-bikes may promote active commuting and recreational cycling,[5 6] and thereby help to reduce physical inactivity, a condition observed in many industrialised countries.[7] Conventional cycling induces various health benefits,[8] which from a public health perspective largely outweigh the risk of exposure to air pollution and traffic accidents.[9 10] However, even though comparable benefits might be expected, the overall effect of e-biking might differ from traditional cycling due to the active motor support. Objectively assessed activity data from larger samples would extend already published data[11 12] and help to better assess the impact of e-biking versus conventional cycling on cycling-related and overall physical activity levels. Policymakers will also benefit from further information on socioeconomic characteristics, purchase motives,[13] replacement of other transport modes,[14] and traffic accident rates,[15 16] to assess the potential of e-bikes as an effective public health measure.

We conducted an observational study in Germany to compare the success rate of e-bike and conventional bicycle users in reaching the World Health Organization (WHO) recommendation for physical activity (150 min/week of moderate-intense physical activity or 75 min/week of vigorous-intense physical activity) using a bicycle. Furthermore, we assessed cycling-related accident rates, subject characteristics and replacement of other transport modes among e-bike users versus conventional bike users.

METHODS

Study design and participants

This was a prospective observational study conducted across Germany. Between February 2017 and December 2019, 2370 volunteers registered for the study by phone, email or on the study website. Of those, 464 could not be included as they did not meet the inclusion/exclusion criteria or did not sign written consent. Of the remaining 1906 participants, 20 from the e-bike group and seven from the bicycle group could not be evaluated because of missing data. Finally, 1250 e-bikers and 629 conventional cyclists were included in the analysis.

This study was carried out following the Declaration of Helsinki. The institutional ethics review board of Hannover Medical School approved the study (No 7237), and written informed consent was obtained before the inclusion of participants.

Recruitment of participants, inclusion and exclusion criteria

To recruit participants, we provided information material to local bicycle shops across Germany cooperating with the largest bike association in Germany (bike shopping cooperative (ZEG)). In addition, the study was advertised in print media and on a specially designed website (http://www.ebike-gesundheit.de/). According to the prestudy defined criteria, we included female and male volunteers aged 18 years or older who had their main residence in Germany. Exclusion criteria were orthopaedic, cardiovascular or other diseases restricting bicycle use or participants with no access to a smartphone or computer with internet access for data transmission. Competitive cyclists were also excluded from the study. Those interested in the study could register by phone, email or directly on the study website. During registration, the following were recorded: full name, gender, contact details, type of bicycle, date of bike purchase, and the response to questions concerning the exclusion criteria.

Group allocation

After registration for the study, eligible participants were sent a declaration of consent, information on data privacy and a medical history questionnaire by post. When meeting the study criteria and signing informed consent, volunteers were included according to their bike use in the e-bike group or the conventional bike group.

Questionnaires

We distributed questionnaires for the evaluation of the health-related quality of life (Short Form 36),[17] for daily physical activity (Freiburger Physical Activity questionnaire),[18] as well as a medical history questionnaire, a specially designed bicycle-specific user questionnaire and an accident documentation form (for more information on questionnaires see online supplemental information).

Observational period and procedures

After inclusion, participants started a consecutive 4-week observational period. All participants received an examination package consisting of the study-related questionnaires and an activity tracker (a smartwatch: Forerunner 35, Garmin, Garching, Germany) with a user manual and individual access data. The package also contained a sticker to attach to the bike to remind users to start and stop the tracking of cycling activities and a flyer with general safety information for cyclists in road traffic.

Participants were asked to record every bicycle ride by selecting and starting the bicycle profile on the smartwatch. Once started, the tracker records the riding time, the travelled distance (by GPS), and the heart rate (HR) via photoplethysmography. After stopping the cycling trip on the tracker, all activity data were saved on the tracker and transmitted to the manufacturer's server (Garmin). Data were then extracted from the Garmin server, pseudonymised, depleted from GPS information about the exact location of the ride, and directly forwarded via an interface (API) to a server at Hannover Medical School, according to current privacy policy legislation. The resulting data were stored and analysed by the Institute of Biometry at Hannover Medical School.

The primary endpoint was the proportion of participants reaching the WHO recommendation for moderate to vigorous physical activity (MVPA) (≥150 min/week moderate intensity or ≥75 min/week vigorous intensity, or a combination of both) by cycling. Based on the recommendation of the American College of Sports Medicine (ACSM),[19] moderate intensity was defined as an activity with a heart rate of 64–76% of the maximum heart rate (HRmax), and vigorous intensity as an activity with a heart rate above 77% of HRmax. The HRmax was calculated for each participant according to Whaley *et al*

1992,[20] considering age, sex, smoking status, body weight and the resting heart rate of participants. Where not all parameters were available, the maximum heart rate was estimated by a simplified calculation (HRmax=208–0.7 x age).[21] For each participant, recorded activity, moderate and vigorous intensity levels were determined at 1 s intervals. Overly long activities (>12 hours/day), very short tracked activities (<10 s) as well as activities with implausible heart rates or speed (mean heart rate ≤60 bpm or ≥200 bpm, mean speed ≤5 km/h or ≥40 km/h) were excluded from the analysis. According to the applicable WHO recommendations at the time of study initiation,[22] a tracked activity was only counted as MVPA if the heart rate stayed above the lower threshold of the respective intensity level (moderate or vigorous) for at least 10 consecutive minutes. If the heart rate fell below the lower threshold for more than 1 min, we considered the preceding and subsequent physical activity to be separate activities. Vigorous activities counted double for the calculation of cycling-related MVPA minutes per week.

Statistical analysis

In the primary analysis, the difference between the study groups in reaching the success rates (cycling at least 150 min/week at MVPA) was tested by X^2-test with a one-sided significance level of 2.5% and a non-inferiority margin of −7.5%. In addition, we performed a sensitivity analysis according to the '2020 WHO guidelines'[23] that states that every MVPA activity counts (regardless of the criterion of at least 10 consecutive minutes). Subgroup analyses were performed for the following subgroups: sex (male/female), age (<53/≥ 53 years), comorbidities (yes/no), body mass index (<25/≥25 kg/m^2), use of heart rate lowering drugs (yes/no), smoking status (yes/no), monthly net income and main purpose of use (every day use; commuting, leisure time, sports-related). Univariate binary logistic regression models were used to identify potential prognostic factors and confounders (p<0.1) influencing the success rate of reaching the physical activity target. In multiple binary logistic regression analyses, we used backward selection to drop independent variables with the highest p value until only those covariates and factors that were significantly associated with reaching the physical activity target remained in the model (p<0.05).

In secondary analyses, categorical and continuous outcomes (such as the average heart rates during cycling, the frequency of cycling (number of cycling trips per week)), and overall cycling time (all cycling activities independent of cycling intensity) were compared between the study groups with a X^2-test and a two-sample t-test, respectively. Analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina, USA) and R version 4.1.0 (R Foundation for Statistical Computing, Vienna, Austria). Data are given as absolute/relative frequencies per category or mean±SD

The sample size calculation was based on a previous feasibility study[24] among workers from companies located in the Hannover area. The study showed that 26% of cyclists reached the WHO criteria for physical activity. With the anticipated 2:1 recruitment ratio, 1200 participants (800 e-bikers, 400 cyclists) needed to be enrolled to show non-inferiority of e-bikers compared with cyclists with a pragmatically justified non-inferiority margin of −7.5%, which was supposed to address the balance between the precision of the estimate and the ability to manage the trial. The one-sided significance level was set to 2.5% and the power to 80%. Another 200 participants were added to take account of possible dropouts, resulting in a total sample size of 1400 participants.

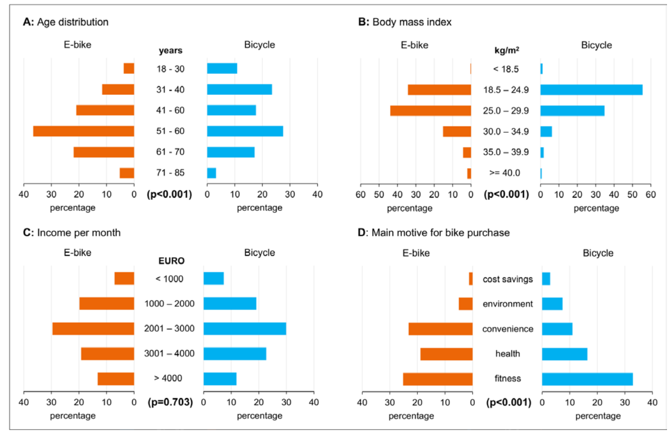

Figure 1 Subject characteristics and motives for bike purchase.

RESULTS

Compared with conventional cyclists, the e-bike group was characterised by older age, body mass index (figure 1A,B), leisure time physical activity, more comorbidities, but less exercise-related physical activity (table 1). Gender distribution, total physical activity and net income (figure 1C) were not different between study groups (for more details, see table 1).

Bike usage characteristics and reaching the physical activity target

The time spent in MVPA during cycling per week was lower for the e-bike group (see figure 2A), with a mean group difference of 69.7 min/week (95% CI 52.5 to 86.8), p<0.001. A higher proportion of conventional bicycle users (35.0%) cycled 150 min or more at MVPA per week in comparison with e-bike users (22.4%) (p<0.001). When analysed as a sensitivity analysis (every MVPA cycling activity counted according to the 2020 WHO guidelines),[23] the differences between cycling groups remained significant (for details, see online supplemental data). The frequency of cycling was different between groups (bicycle: 5.9±5.6 trips/week; e-bike: 3.8±4.4 trips/week; p<0.001). The overall cycling time was higher for the bicycle group (see figure 2B) with a mean group difference of 24.8 min/week (95% CI 9.0 to 40.7), p<0.001 whereas the average duration per trip was longer in the e-bike group (bicycle: 26.2±26.2 min/

Table 1 Baseline characteristics of participants

Characteristics	Total	E-bikers	Cyclists	P value
Participants, n	1879	1250	629	
Female, n (%)	598 (31.8%)	414 (33.1%)	184 (29.3%)	
Male, n (%)	1281 (68.2%)	836 (66.9%)	445 (70.7%)	0.089
Age, years	52.3 (12.4)	54.2 (11.4)	48.3 (13.4)	<0.0001
Body weight, kg	83.0 (16.9)	84.8 (17.4)	79.4 (15.2)	<0.0001
Body mass index, kg/m^2	26.4 (4.5)	27.1 (4.6)	25.0 (3.9)	<0.0001
Resting heart rate, bpm	60.0 (8.2)	60.7 (8.1)	58.7 (8.2)	<0.0001
Employment				
Full-time, n (%)	1118 (64.5%)	703 (61.5%)	415 (70.6%)	
Part-time, n (%)	277 (16.0%)	194 (17.0%)	83 (14.1%)	
Unemployed, n (%)	337 (19.5%)	247 (21.6%)	90 (15.3%)	0.001
Smoker				
Smoker, n (%)	142 (7.6%)	109 (8.8%)	33 (5.2%)	
Non-smoker, n (%)	1730 (92.4%)	1134 (91.2%)	596 (94.8%)	0.007
Comorbiditiesp				
Coronary heart disease, n (%)	101 (5.4%)	80 (6.4%)	21 (3.4%)	0.004
Stroke, n (%)	29 (1.5%)	23 (1.8%)	6 (1.0%)	0.123
Hypertension, n (%)	465 (24.7%)	364 (29.1%)	101 (16.2%)	<0.0001
Diabetes mellitus type 2, n (%)	68 (3.6%)	58 (4.6%)	10 (1.6%)	0.001
Asthma bronchiale/COPD, n (%)	122 (6.5%)	98 (7.8%)	24 (3.8%)	0.001
Allergies, n (%)	535 (28.5%)	340 (27.2%)	195 (31.2%)	0.151
Any other stated comorbidity, n (%)	940 (50.0%)	662 (53.0%)	278 (44.5%)	0.001
Heart rate lowering drugs				
No, n (%)	1493 (83.5%)	940 (79.8%)	553 (90.8%)	
Yes, n (%)	294 (16.5%)	328 (20.3%)	56 (9.2%)	<0.0001
Health-related quality of life				
SF-36, physical sum score, points	52.1 (7.2)	51.3 (7.6)	53.6 (6.1)	<0.0001
SF-36, mental sum score, points	51.4 (8.2)	51.4 (8.4)	51.5 (7.7)	0.755
Physical activity level				
Total physical activity, MET-h/wk	54.9 (56.9)	54.8 (54.6)	55.2 (61.1)	0.880
Leisure time activity, MET-h/wk	20.3 (38.7)	22.2 (43.9)	16.8 (25.7)	0.009
Exercise activity, MET-h/wk	13.3 (26.0)	12.2 (21.6)	15.4 (32.6)	0.022

Differences between bike groups were analysed with Student's t-test for unpaired samples for continuous variables or the X^2 test for categorical variables; data are n (%) or mean (SD).
COPD, chronic obstructive pulmonary disease; MET, metabolic equivalent of task; SF-36, Short Form 36 questionnaire.

trip, e-bike: 32.7±35.4 min/trip; mean group difference: 6.5 min/trip (95% CI 3.4 to 9.6)) The absolute heart rate during cycling was higher in the bicycle group (bicycle: 119.3±13.7 bpm; e-bike: 111.3±13.9 bpm; mean group difference: 8.0 bpm (95% CI 6.5 to 9.5), p<0.001), as well as the relative heart rate expressed as a percentage of maximum heart rate (see figure 2C),

Prognostic factors for reaching the physical activity target

To determine prognostic factors which influence the success rate of reaching the physical activity target (150 min of MVPA per week), we included the study group (e-bike vs bicycle) and all potential prognostic factors (p<0.1) found in univariate analyses (for details see online supplemental table S1) into multiple binary logistic regression models. In the full model, the study group (e-bike vs bicycle), age (<53/≥53 years), sex (male/female), comorbidities (yes/no), and the bike usage pattern 'sport-related use' and 'commuting' turned out to be significant predictive factors for the rate of reaching the physical activity target (see online supplemental table S2). In this model, the adjusted odds of reaching 150 min of MVPA per week were lower for e-bike users

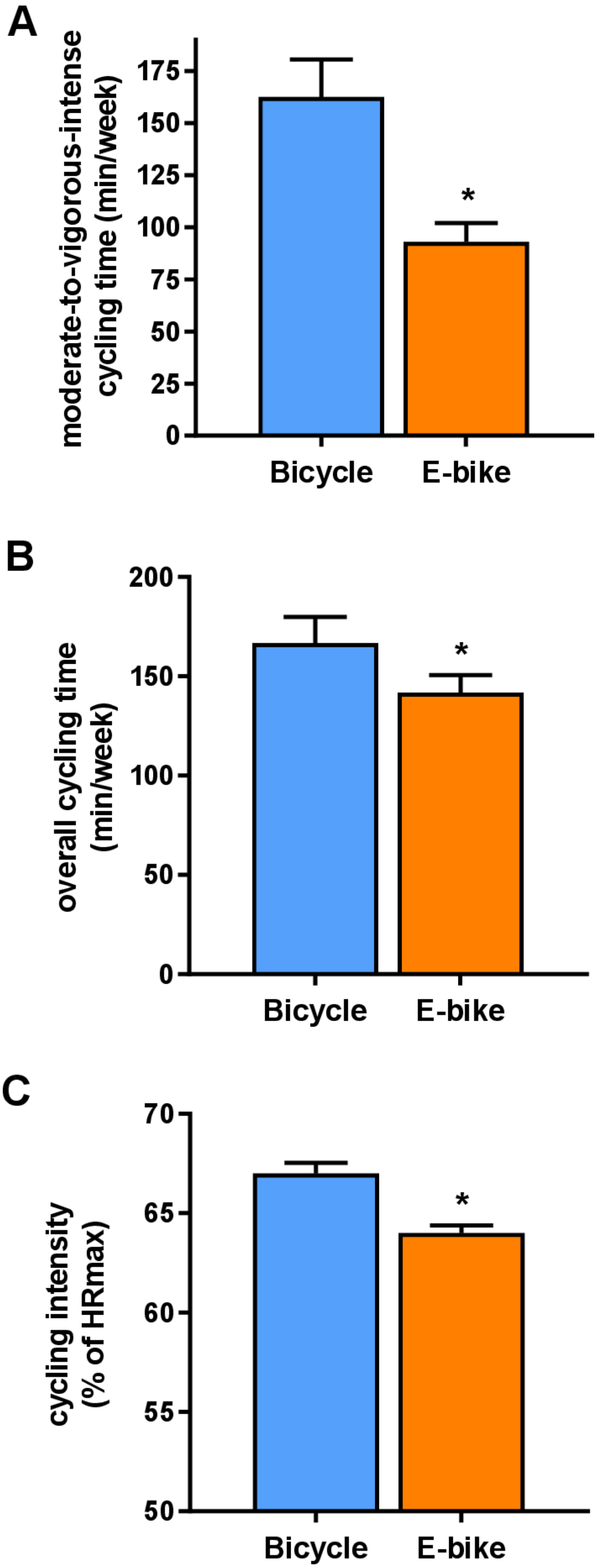

Figure 2 Time cycled at moderate-to-vigorous intensity. (A) Overall cycling duration per week and (B) intensity of cycling (percentage of maximum heart rate), (C) all assessed with activity trackers during the 4- week observational period. *p<0.001 between groups.

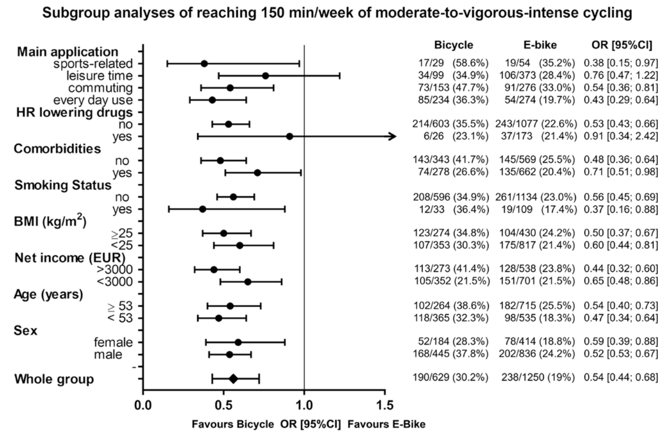

Figure 3 Frequencies of participants reaching 150 min of moderate-to-vigorous intense cycling per week (in absolute numbers and per cent) for conventional cyclists and e-bikers, and the ORs (95% CI) for reaching the physical activity target when comparing electrically assisted cycling with conventional cycling. Lower ORs indicate a lower probability of e-bikers reaching the physical activity target.

than bicycle users (OR=0.56, 95% CI 0.43 to 0.72). After backward selection (subsequently dropping independent variables with the highest p value), the study group, age, sex, comorbidities and the bike usage pattern, sport-related use and commuting, remained significant (see online supplemental table S2). Goodness-of-fit for the final model was assessed using the Hosmer-Lemeshow test, indicating a good model fit, $\chi^2(8) = 4.43$, p=0.816.

When analysed within subgroups, we observed a significantly lower probability of reaching the physical activity target when using an e-bike than a conventional bicycle for all subgroups, except for subjects with heart rate lowering medication and those using the bike for sports-related purposes or leisure time activities (see figure 3).

Motives for bike purchase and replacement of other transport modes

The most commonly mentioned motive when asked for purchasing their bicycle or e-bike was physical fitness (figure 1D). The second most popular motive in the e-bike group was convenience (ease of cycling), which was mentioned twice as often as in the bicycle group. Reasons such as environment or cost savings played minor roles as motives for purchase (figure 1D). E-bikers replace cars more than bicycle riders, and bicycle riders replace urban transport for going to work more than e-bikers. No differences between study groups were observed for the replacement of walks with cycling (see table 2).

Road traffic accidents

Participants reported 272 accidents or near-accidents. Six of these had to be excluded owing to incomplete information. Overall, 109 accidents and 157 near accidents occurred during the 12-month period. There were no significant differences between the groups regarding accidents or near-accidents (table 3). Age was similar for

Table 2 Replacement of other transport modes by bicycles or e-bikes

	Replacement of private car trips*			Replacement of public transport†			Replacement of walks‡		
	E-bikers (n=1250)	Cyclists (n=629)	P value	E-bikers (n=1250)	Cyclists (n=629)	P value	E-bikers (n=1250)	Cyclists (n=629)	P value
Way to work									
Missing, n	256	105		256	105		256	105	
No, n (%)	687 (69.1%)	427 (81.5%)		906 (91.1%)	453 (86.5%)		965 (97.1%)	506 (96.6%)	
Yes, n (%)	307 (30.9%)	97 (18.5%)	<0.0001	88 (8.9%)	71 (13.5%)	0.005	29 (2.9%)	18 (3.4%)	0.579
Purchase of food/ shopping									
Missing, n	256	105		256	105		256	105	
No, n (%)	677 (68.1%)	437 (83.4%)		973 (97.9%)	505 (96.4%)		922 (92.8%)	480 (91.6%)	
Yes, n (%)	317 (31.9%)	87 (16.6%)	<0.0001	21 (2.1%)	19 (3.6%)	0.080	72 (7.2%)	44 (8.4%)	0.421
Leisure time									
Missing, n	256	105		256	105		256	105	
No, n (%)	738 (74.2%)	450 (85.9%)		941 (94.7%)	484 (92.4%)		898 (90.3%)	484 (92.4%)	
Yes, n (%)	256 (25.8%)	74 (14.1%)	<0.0001	53 (5.3%)	40 (7.6%)	0.075	96 (9.7%)	40 (7.6%)	0.189
Way to sport activities									
Missing, n	256	105		256	105		256	105	
No, n (%)	806 (81.1%)	468 (89.3%)		977 (98.3%)	507 (96.8%)		942 (94.8%)	494 (94.3%)	
Yes, n (%)	188 (18.9%)	56 (10.7%)	<0.0001	17 (1.7%)	17 (3.2%)	0.055	52 (5.2%)	30 (5.7%)	0.686
Others									
Missing, n	256	105		256	105		256	105	
No, n (%)	864 (86.9%)	493 (94.1%)		974 (98.1%)	508 (96.9%)		962 (96.8%)	507 (96.8%)	
Yes, n (%)	130 (13.1%)	31 (5.9%)	<0.0001	20 (2.0%)	16 (3.1%)	0.205	32 (3.2%)	17 (3.2%)	0.979

*Question: “Since you used your bike, which journeys with your private motorised vehicle (car) have you replaced with your bicycle/e-bike?“
†Question: “Since you used your bike, which journeys on foot have you replaced with your bicycle/e-bike?“.
‡Question: “Since you used your bike, which journeys by public transport have you replaced with your bicycle/ e-bike?" Differences between groups were analysed with the X^2 test. Data are n (%).

both types of accidents between study groups. Among women, accidents occurred more often for e-bikers than for conventional bike users. After controlling for potential prognostic factors and confounders, the study group and overall cycling time predicted road traffic accidents in multiple binary regression analysis, with e-bikers having a higher probability of having a traffic accident (OR=1.63, 95% CI 1.02 to 2.58), p=0.039) than conventional cyclists (see online supplemental table S6). For near-accidents, older age, frequency of cycling and the overall cycling time were predictors of road traffic accidents but not the study group (see online supplemental table S8). Regarding accident opponents, no significant differences were observed between study groups (table 3).

DISCUSSION

We investigated the impact of e-bikes on cycling-related and overall physical activity, traffic accident rates and user characteristics in a nationwide cohort in Germany. Our main finding is that e-biking is characterised by less riding duration and lower riding intensity, leading to less cycling spent at MVPA than conventional cycling. The risk for road traffic or near-accidents was similar to that for conventional bikes. Motives for purchasing e-bikes are mainly for alleviating physical strain during cycling and health promotion, which is consistent with the idea that e-bikes might help specifically older or overweight users or individuals with reduced mobility to overcome barriers to using a bicycle in everyday life.

Bike usage patterns and prognostic factors for reaching the physical activity target

Current physical activity guidelines emphasise the importance of activities not traditionally perceived as exercise, such as commuting on foot or by bicycle, to incorporate small bouts of movement into everyday routine.[23 25] The increased popularity of e-bikes might promote active transportation and help individuals meet current activity recommendations. To date, only one European-wide study (PASTA) has estimated the activity-related energy expenditure of e-biking, observing energy expenditure comparable to that of conventional cyclists.[11] It should be noted that the PASTA study used online surveys and not objective measures like activity trackers to assess the frequency, duration and intensity of cycling. as done in

Table 3 Road traffic accidents with e-bikes or conventional bicycles

	E-bikers	Cyclists	p-value
Accidents			
Accident cases/participants	76/1250 (6.1%)	26/629 (4.1%)	0.080
Age of cases (years)	51.9 (12.2)	49.5 (11.7)	0.431
Subgroup women			
Accident cases/participants	29/414 (7.0%)	3/184 (1.7%)	0.026
Subgroup men			
Accident cases/participants	47/836 (5.6%)	23/445 (5.2%)	0.901
Accident opponent			
Without opponent (accidents/total accidents)	54/79 (68.4%)	21/30 (70%)	0.868
Car (accidents/total accidents)	13/79 (16.5%)	8/30 (26.7%)	0.227
Truck/bus (accidents/total accidents)	1/79 (1.3%)	1/30 (3.3%)	0.473
Motorcycle (accidents/total accidents)	0/79 (0.0%)	0/30 (0.0%)	–
Bicycle (accidents/total accidents)	6/79 (7.6%)	0/30 (0.0%)	0.120
Pedestrian (accidents/total accidents)	5/79 (6.3%)	0/30 (0.0%)	0.158
Near accidents			
Accident cases/participants	97/1250 (7.8%)	60/629 (9.5%)	0.187
Age of cases (years)	50.2 (10.6)	47.7 (11.4)	0.085
Subgroup women			
Accident cases/participants	30/414 (7.2%)	9/184 (4.9%)	0.369
Subgroup men			
Accident cases/participants	67/836 (8.0%)	51/445 (11.4%)	0.053

The data correspond to the frequencies (%) or the mean; the proportions were calculated within the category of the type of bike. Differences between groups were analysed with the X^2 test for categorical variables, and Student's t-test for continuous variables; data are n (%) or mean (SD).

our study. In contrast, previous small-scale studies[12 26–28] have reported that using an e-bike led to shorter trip duration and lower cycling intensity, prompting the question of whether activity-related exposure is sufficient to achieve targeted health effects. However, since these studies applied experimental designs with fixed travel distances or fixed levels of mechanical motor support, the results are difficult to extrapolate to a real-world setting.

In our study, overall cycling time, frequency of bike riding and heart rate during cycling were lower for e-bikers, while cycling time per trip was higher for e-bikers. Hence, cycling spent at MVPA was also less for e-bikers, irrespective of the calculation of MVPA (WHO 2010: at least 10 consecutive minutes of MVPA[22] or WHO 2020: counting every activity bout at MVPA).[23] These outcomes contradict the results of the above-mentioned PASTA study in which physical activity levels (estimated energy expenditure) were reported to be similar for e-bikers and conventional bikers.[11] This might be explained by using self-reported versus objective measures of trip numbers, trip duration and cardiovascular effort. Furthermore, the exclusive focus on participants from large cities (eg, London, Barcelona, Rome), in contrast to our investigation, which included rural and urban areas reflecting diverse infrastructures, might limit the generalizability and partly explain the differences in our findings.

Participants' characteristics and motives for bike purchase and use

The energy expended during activity, a product of activity duration and intensity, is a well-established marker of physical activity-related health benefits.[29] Given the observed higher energy expenditure when using a traditional bicycle, it appears we should recommend bicycles rather than e-bikes to attain optimised health effects. However, this view neglects the fact that certain individuals make a deliberate choice to purchase an e-bike, who would not otherwise consider conventional cycling.[13] The participant characteristics of our cohort suggest that e-biking is of interest, particularly for those who will benefit the most for health-related fitness—namely, older users, overweight and obese individuals or those with health-related limitations and fewer exercise activities. Indeed, stated purchase motives indicate that e-bikers appreciate the ease of use and comfort of e-bikes and the opportunity to increase their health and fitness, which confirms previous findings that e-biking provides the option to continue cycling despite physical limitations and has the potential to maintain physical activity and fitness.[5]

Replacement of other transport modes

An essential aspect when assessing the overall health effects of activity interventions or exercise-supporting electrical devices is the effect on other daily activities. Previous studies have suggested that for e-bike users, other physical activities are not significantly affected—that is, there does not appear to be an activity substitution effect.[30 31] Our activity questionnaire data support these results, as we did not observe differences between the bike groups for total daily physical activity or substantial replacement of walking journeys by bikes. From an ecological, infrastructural and health perspective, it would be desirable if the increasing sale of e-bikes would (at least partly) lead to replacing CO_2-emitting motorised vehicles. The degree to which e-bikes replace other transport modes varies across studies. Current evidence suggests that private cars and conventional bicycles are the most substituted transport modes when using an e-bike.[5] Our survey data indeed strengthen previous findings that e-bikers are most likely to replace car journeys with their e-bike, with fewer replacing trips conducted by foot or public transport.

Road traffic accidents

WHO sustainable development goal (SDG) 3.6 was to halve the number of global deaths and injuries from road traffic accidents by 2020.[32] Recent reports from the European and Asian regions indicate that the SDG 3.6 is unlikely to be reached.[15 33] Since an electrically assisted bicycle usually goes faster and weighs about 30% to 50% more than a conventional bicycle,[26] it could be postulated that its handling is more difficult, and accidents are more likely to occur. Indeed, there are reports that particularly those who switch from conventional bicycles to e-bikes might have an increased risk of collisions due to higher speed and more unexpected and sharp braking manoeuvres.[34] Looking at the crude frequencies of traffic accidents, we observed no significant differences between the two bike groups. However, when controlled for confounders and potential prognostic factors e-biking and longer cycling time were found to be predictors of traffic accidents, which should be taken into account when considering e-bikes as an effective public health tool. Our results confirm earlier data[16] that women riding an e-bike might have a greater risk of traffic accidents than women on conventional bikes. The reasons for this gender difference are not yet clear but might include more difficulties for women with balance and higher speed when riding an e-bike, and women are more often novel e-bike users.[16]

Limitations and strengths

Our study has strengths and limitations. As the first large-scale study in this context, we investigated the characteristics, motives and usage patterns of e-bikers versus conventional bikers under real-life conditions using objective activity measures. As for any real-world data, we cannot rule out the possibility of data artefacts or incorrect application of the activity tracker by the study participants. The method used to assess HR by the smartwatch is not as accurate as assessment of HR with an ECG or a chest belt. As a further limitation, maximum HR was not measured during an exhaustive exercise test but calculated by published formula, which might affect the individual assessment of time spent at MVPA.

CONCLUSION

In conclusion, we observed that e-bike use is associated with a lower probability of reaching WHO targets for moderate-to-vigorous physical activity than bicycle use. Therefore, the expected health effects might be higher for bicycle users, which is an important factor for policymakers in the discussion on subsidising e-bikes at the state level. However, the increasing attractiveness and popularity of e-bikes might facilitate recreational cycling and active commuting, particularly for those who are limited by age- or illness-associated constrictions and who otherwise would not opt to use a bicycle. Further research on users' motives and possible replacement of other transport modes is necessary to shed light on whether e-bikes, as an active form of electromobility, could feasibly provide a relevant contribution to mitigating traffic congestion and air pollution promote active living.

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Contributors J-MGS, JZ, UT, HJ and AK planned and designed the study; HTB, JB and CCvR recruited participants. JB, CCvR and TS collected the data; MK, DH, and SHä processed the activity device data and questionnaire data; and JZ, HJ and TS collected and analysed the traffic accident surveys; AK calculated the sample size, and DH and SHä were responsible for the statistical analyses. SH and HTB wrote the first draft of the manuscript. AK, J-MGS, MK and UT contributed to the discussion and reviewed/edited the manuscript. UT, SH and AK have verified the underlying data. All authors had full access to all data, participated in data interpretation, approved the final manuscript, and agreed to submit for publication. SH is the guarantor for the overall content of the study.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the ethics committee of Hannover Medical School, ID: 7237. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Data will be shared with researchers who provide a methodologically sound proposal to achieve aims in the approved proposal. Proposals should be directed to sportmedizin@mh-hannover.de to gain access, data requestors will need to sign a data access agreement.

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Supplementary material

Impact of electrically-assisted bicycles on physical activity and traffic accident risk: a prospective observational study.

METHODS

General information

The Institute of Sports Medicine at Hannover Medical School in cooperation with the Institute of Biostatistics was responsible for the study design, statistical planning, inclusion of study participants, data collection and analysis, as well as the preparation of the manuscript. The Center for Health Economics Research Hannover and the Accident Research Unit contributed to the definition of the study design, assessed road traffic accidents and assisted the data analyses. The statistical report was provided to the Institute of Sports Medicine, who were responsible for data interpretation and writing the manuscript.

Questionnaires:

The SF-36 questionnaire measures QoL with eight subscales resulting in two sum scales, the mental- and physical component score of QoL. For both scales, a score of 0 points represents a minimum and a score of 100 points a maximum quality of life. The Freiburger activity questionnaire estimates the total and exercise-related physical activity of adults, both of which are specified as metabolic equivalents of task (MET)-hours per week. The medical history questionnaire included questions about general characteristics (e.g. age, workplace, and income), health status (e.g. comorbidities, musculoskeletal disorders), anthropometric data, and motion behavior (daily routines by car, bicycle, public transport etc.) The study specific user questionnaire includes general information on the bike used (bike type, purchase price, planned bike use, motive for purchase), as well as usual frequency of use, distances travelled, and transportation options. The accident sheet provided the opportunity to report traffic incidents and health-related consequences per post or online. A distinction was made between a near-accident (a critical situation in which an emergency maneuver (braking/ steering) prevented an accident) and an accident (defined as a collision or fall while cycling that resulted in injury or damage). The participant were asked to complete all documentation and return it to the study center.

Univariate analysis and prognostic factors for reaching the physical activity target

Table S1. Univariate binary logistic regression for reaching the physical activity target

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Age	>= 53 years	284/979 (29.0%)	<53 years	216/900 (24.0%)	0.77 [0.63; 0.95]	0.014
Children	>1	110/380 (28.9%)	0-1	382/1475 (25.9%)	0.86 [0.67; 1.10]	0.230
BMI	Overweight / obesity	272/1091 (24.9%)	Underweight / normal weight	227/783 (29.0%)	1.23 [1.00; 1.51]	0.050
Concomitant medication	No	418/1493 (28.0%)	Yes	59/294 (20.1%)	0.65 [0.48; 0.88]	0.005
Education	>= higher school certificate	332/1271 (26.1%)	<= secondary school certificate	167/604 (27.7%)	1.08 [0.87; 1.34]	0.484
Salary	>= 3000€	241/811 (29.7%)	< 3000€	256/1053 (24.3%)	0.76 [0.62; 0.93]	0.009
Sex	Female	130/598 (21.7%)	Male	370/1281 (28.9%)	1.46 [1.16; 1.84]	0.001
HF reducing medication	No	457/1680 (27.2%)	Yes	43/199 (21.6%)	0.74 [0.52; 1.05]	0.092
Buying motive	Other Aspects	245/815 (30.1%)	Health Improvement	233/675 (34.5%)	1.23 [0.99; 1.53]	0.067
Comorbidities	No	288/912 (31.6%)	Yes	209/940 (22.2%)	0.62 [0.50; 0.76]	<0.001
Physical disabilities/disorders	No	56/186 (30.1%)	Yes	444/1689 (26.3%)	0.83 [0.59; 1.15]	0.264
Primary bike use*	Every day use	139/508 (27.4%)	Leisure	140/472 (29.7%)	1.12 [0.85; 1.48]	0.517
			Commuting	164/429 (38.2%)	1.64 [1.25; 2.16]	0.087
			Sport	36/83 (43.4%)	2.03 [1.26; 3.27]	0.028
			Other	3/13 (23.1%)	0.80 [0.22; 2.94]	0.400
Smoking status	No	469/1730 (27.1%)	Yes	31/142 (21.8%)	0.75 [0.50; 1.13]	0.173
Sport points (physical activity questionnaire)	>= 43	275/939 (29.3%)	< 43	224/933 (24.0%)	0.76 [0.62; 0.94]	0.009
Study group	Conventional cycling	220/629 (35.0%)	E-bike	280/1250 (22.4%)	0.54 [0.43; 0.66]	<0.001

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable).
* type III F-test was performed for primary bike use (p=0.0008)

Table S2. Multiple binary logistic regression model for reaching the physical activity target

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	0.56 [0.43; 0.72]	<0.001	0.52 [0.41; 0.66]	<0.001
Age (>=53 years)	<53 years	0.60 [0.47; 0.78]	0.001	0.58 [0.45; 0.74]	<0.001
BMI (underweight / normal weight)	Overweight / obesity	1.03 [0.80; 1.31]	0.835		
Sex (female)	Male	1.34 [1.02; 1.74]	0.033	1.37 [1.06; 1.77]	0.017
Salary (>= 3000€)	< 3000€	0.89 [0.71; 1.13]	0.344		
HF reducing medication (no)	Yes	0.90 [0.59; 1.36]	0.618		
Comorbidities (no)	Yes	0.65 [0.51; 0.83]	<0.001	0.64 [0.51; 0.80]	<0.001
Buying motive (pragmatic)	Health	1.22 [0.96; 1.55]	0.100		
Sport points in the physical activity questionnaire (>=43 pts)	< 43 pts	0.81 [0.64; 1.03]	0.083		
Primary bike use** (everyday use)	Leisure time	1.27 [0.94; 1.73]	0.125	1.26 [0.93; 1.70]	0.129
	Commuting	1.93 [1.43; 2.62]	<0.001	1.91 [1.42; 2.59]	<0.001
	Sports-related	2.18 [1.32; 3.62]	0.003	2.26 [1.37; 3.73]	0.001
	Other	0.94 [0.24; 3.62]	0.928	0.94 [0.24; 3.63]	0.932

Hosmer-Lemeshow test for the final model): $\chi^2(8) = 4.43$, $p = 0.816$ * multiple binary logistic regression to determine prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.
** type III F-test was performed for primary bike use and was statistically significant before and after backward selection

($p<.001$)

Sensitivity analysis for MVPA cycling activities according to the 2020 WHO guidelines for physical activity (PA)

In addition to our primary analysis relating to the "2010 WHO global recommendations on physical activity for health" [1] which stated that moderate- and vigorous-intensity activity (MVPA) should be performed in bouts of at least 10 minutes duration, we conducted a sensitivity analysis according to the recently published "2020 WHO guidelines on physical activity and sedentary behavior" [2].

In contrast to the WHO recommendation published in 2010, the 2020 WHO guideline states that now MVPA bouts of any duration count towards the calculation of MVPA minutes per week. Therefore, we reanalyzed our data and counted any cycling activity if the heart rate was above the lower individual threshold of the respective intensity level (moderate or vigorous), and present this as sensitivity analysis for the primary outcomes.

Cycling at MVPA per week, and reaching the target of cycling 150 min at MVPA per week (according to the 2020 WHO guidelines for PA)

Time spent at MVPA during cycling per week was higher for the bicycle group (bicycle: 166.4 ± 195.6 min/week; e-bike: 105.3 ± 139.0 min/week) with a mean difference between groups of 61.2 min/week [CI95% 45.8; 76.5], $p<0.001$. A higher proportion of conventional bicycle users (41.2%) cycled 150 min or more at MVPA per week when compared to e-bike users (27.2%) ($p<0.001$).

Univariate analysis and prognostic factors for reaching the physical activity target (according to the 2020 WHO guidelines for PA)

Table S3. Univariate binary logistic regression for reaching the physical activity target

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi^2-Test)
Age	>= 53 years	341/979 (34.8%)	<53 years	258/900 (28.7%)	0.75 [0.62; 0.91]	0.004
Children	>1	129/380 (34.0%)	0-1	461/1475 (31.3%)	0.88 [0.70; 1.12]	0.315
BMI	Overweight / obesity	328/1091 (30.1%)	Underweight / normal weight	270/783 (34.5%)	1.22 [1.01; 1.49]	0.043
Concomitant medication	No	494/1493 (33.1%)	Yes	71/294 (24.2%)	0.64 [0.48; 0.86]	0.003
Education	>= higher school certificate	413/1271 (32.5%)	<= secondary school certificate	185/604 (30.6%)	0.92 [0.74; 1.13]	0.418
Salary	>= 3000€	276/811 (34.0%)	< 3000€	318/1053 (30.2%)	0.84 [0.69; 1.02]	0.079
Sex	Female	164/598 (27.4%)	Male	435/1281 (34.0%)	1.36 [1.10; 1.68]	0.005
HF reducing medication	No	547/1680 (32.6%)	Yes	52/199 (26.1%)	0.73 [0.53; 1.02]	0.067
Buying motive	Other Aspects	300/815 (36.8%)	Health Improvement	271/675 (40.2%)	1.15 [0.93; 1.42]	0.187
Comorbidities	No	337/912 (37.0%)	Yes	258/940 (27.5%)	0.65 [0.53; 0.79]	<.001
Physical disabilities/disorders	No	58/186 (31.2%)	Yes	541/1689 (32.0%)	1.04 [0.75; 1.44]	0.815
Primary bike use*	Every day use	183/508 (36.0%)	Leisure	161/472 (34.1%)	0.92 [0.71; 1.20]	0.089
			Commuting	191/429 (44.5%)	1.43 [1.10; 1.85]	0.200
			Sport	39/83 (47.0%)	1.57 [0.99; 2.51]	0.175
			Other	5/13 (38.5%)	1.11 [0.36; 3.44]	0.894
Smoking status	No	562/1730 (32.5%)	Yes	37/142 (26.1%)	0.73 [0.50; 1.08]	0.116
Sport points (activity questionnaire)	>= 43	324/939 (34.5%)	< 43	273/933 (29.3%)	0.79 [0.65; 0.95]	0.015
Study group	Conventional cycling	259/629 (41.2%)	E-bike	340/1250 (27.2%)	0.53 [0.44; 0.65]	<.001

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). * type III F-test was performed for primary bike use (p=0.007)

Table S4. Multiple binary logistic regression model for reaching the physical activity target

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	0.54 [0.42; 0.69]	<0.001	0.51 [0.40; 0.65]	<0.001
Age (>=53 years)	<53 years	0.53 [0.42; 0.68]	<0.001	0.52 [0.41; 0.67]	<0.001
BMI (underweight / normal weight)	Overweight / obesity	1.00 [0.79; 1.27]	0.968		
Sex (female)	Male	1.30 [1.01; 1.67]	0.044	1.30 [1.02; 1.66]	0.035
Salary (>= 3000€)	< 3000€	0.97 [0.78; 1.22]	0.818		
HF reducing medication (no)	Yes	0.84 [0.57; 1.25]	0.400		
Comorbidities (no)	Yes	0.68 [0.54; 0.86]	0.001	0.67 [0.53; 0.83]	<0.001
Buying motive (pragmatic)	Health	1.15 [0.92; 1.45]	0.219		
Sport points (physical activity questionnaire) (>=43 pts)	< 43 pts	0.88 [0.69; 1.10]	0.261		
Primary bike use** (every day use)	Leisure time	1.00 [0.75; 1.34]	0.974	1.00 [0.75; 1.33]	0.984
	Commuting	1.71 [1.28; 2.29]	<0.001	1.70 [1.27; 2.27]	<0.001
	Sports-related	1.75 [1.06; 2.88]	0.027	1.79 [1.10; 2.93]	0.020
	Other	0.92 [0.26; 3.22]	0.900	0.94 [0.27; 3.27]	0.922

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(8) = 7.72$, $p = 0.461$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.

Univariate and multiple analysis for prognostic factors for having at least one road traffic accident or near-accident

First, univariate binary logistic regression models were used to identify potential prognostic factors and confounders ($p<0.1$) influencing the success rate of having at least one road traffic accident (Table S5) or near-accident (Table S7), respectively. Then, potential prognostic factors were included in multiple binary logistic regression analysis and backward selection was used to drop independent variables with the highest p-value until only covariates and factors remained in the model that were significantly associated ($p<0.05$) with having at least one road traffic accident (Table S6) or near-accident (Table S8), respectively.

Table S5. Univariate binary logistic regression for having at least one traffic accident

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi^2-Test)
Age	>= 53 years	47/979 (4.8%)	<53 years	55/900 (6.1%)	1.29 [0.86; 1.93]	0.212
Sex	female	32/598 (5.4%)	male	70/1281 (5.5%)	1.02 [0.67; 1.57]	0.919
Overall cycling time	<= 110 min/wk	35/941 (3.7%)	> 110 min/wk	67/938 (7.1%)	1.99 [1.31; 3.03]	0.001
Cycling frequency	<= 3 trips/wk	37/924 (4.0%)	> 3 trips/wk	65/955 (6.8%)	1.75 [1.16; 2.65]	0.008
Study group	Conventional cycling	26/629 (4.1%)	E-bike	76/1250 (6.1%)	1.50 [0.95; 2.37]	0.080

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the probability of having at least one accident (dependent variable).

Table S6. Multiple binary logistic regression model for having at least one traffic accident

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	**p-value (Chi²-Test)**	**Odds Ratio [CI 95%]**	**p-value (Chi²-Test)**
Study Group (cycling)	E-bike	1.63 [1.02; 2.58]	0.039	1.59 [1.00; 2.51]	0.048
Overall cycling time (<= 110 min/wk)	> 110 min/wk	1.74 [0.96; 3.17]	0.069	2.05 [1.35; 3.13]	0.001
Cycling frequency (<= 3 trips/wk)	> 3 trips/wk	1.26 [0.69; 2.28]	0.451		

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(2) = 1.66$, $p = 0.437$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the probability of having at least one accident (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with p<0.05 remained in the "Final model" as reported above.

Table S7. Univariate binary logistic regression for having at least one near-accident

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Age	>= 53 years	57/979 (5.8%)	<53 years	77/900 (8.6%)	1.51 [1.06; 2.16]	0.022
Sex	female	33/598 (5.5%)	male	101/1281 (7.9%)	1.47 [0.98; 2.2]	0.065
Overall cycling time	<= 110 min/wk	38/941 (4.0%)	> 110 min/wk	96/938 (10.2%)	2.71 [1.84; 3.99]	<0.001
Cycling frequency	<= 3 trips/wk	35/924 (3.8%)	> 3 trips/wk	99/955 (10.4%)	2.94 [1.98; 4.37]	<0.001
Study group	Conventional cycling	48/629 (7.6%)	E-bike	86/1250 (6.9%)	0.89 [0.62; 1.29]	0.550

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the probability of having at least one near-accident (dependent variable).

Table S8. Multiple binary logistic regression model for having at least one near-accident

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	1.12 [0.77; 1.64]	0.548		
Overall cycling time (<= 110 min/wk)	> 110 min/wk	1.71 [1.00; 2.92]	0.051	1.74 [1.02; 2.98]	0.043
Cycling frequency (<= 3 trips/wk)	> 3 trips/wk	2.02 [1.16; 3.51]	0.013	1.97 [1.14; 3.41]	0.015
Sex (female)	Male	1.45 [0.96; 2.18]	0.078		
Age (>=53 years)	<53 years	1.61 [1.12; 2.33]	0.010	1.57 [1.10; 2.25]	0.014

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(4) = 1.689$, $p = 0.793$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the probability of having at least one near-accident (dependent variable). After univariate analyses, multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.

References

1. World Health Organization. Global Recommendations on Physical Activity for Health 2010 [Available from: https://www.who.int/dietphysicalactivity/global-PA-recs-2010.pdf accessed 12 Feb 2021.
2. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine* 2020;54:1451-62.

Supplementary material

Impact of electrically-assisted bicycles on physical activity and traffic accident risk: a prospective observational study.

METHODS

General information

The Institute of Sports Medicine at Hannover Medical School in cooperation with the Institute of Biostatistics was responsible for the study design, statistical planning, inclusion of study participants, data collection and analysis, as well as the preparation of the manuscript. The Center for Health Economics Research Hannover and the Accident Research Unit contributed to the definition of the study design, assessed road traffic accidents and assisted the data analyses. The statistical report was provided to the Institute of Sports Medicine, who were responsible for data interpretation and writing the manuscript.

Questionnaires:

The SF-36 questionnaire measures QoL with eight subscales resulting in two sum scales, the mental- and physical component score of QoL. For both scales, a score of 0 points represents a minimum and a score of 100 points a maximum quality of life. The Freiburger activity questionnaire estimates the total and exercise-related physical activity of adults, both of which are specified as metabolic equivalents of task (MET)-hours per week. The medical history questionnaire included questions about general characteristics (e.g. age, workplace, and income), health status (e.g. comorbidities, musculoskeletal disorders), anthropometric data, and motion behavior (daily routines by car, bicycle, public transport etc.) The study specific user questionnaire includes general information on the bike used (bike type, purchase price, planned bike use, motive for purchase), as well as usual frequency of use, distances travelled, and transportation options. The accident sheet provided the opportunity to report traffic incidents and health-related consequences per post or online. A distinction was made between a near-accident (a critical situation in which an emergency maneuver (braking/ steering) prevented an accident) and an accident (defined as a collision or fall while cycling that resulted in injury or damage). The participant were asked to complete all documentation and return it to the study center.

Univariate analysis and prognostic factors for reaching the physical activity target

Table S1. Univariate binary logistic regression for reaching the physical activity target

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi^2-Test)
Age	>= 53 years	284/979 (29.0%)	<53 years	216/900 (24.0%)	0.77 [0.63; 0.95]	0.014
Children	>1	110/380 (28.9%)	0-1	382/1475 (25.9%)	0.86 [0.67; 1.10]	0.230
BMI	Overweight / obesity	272/1091 (24.9%)	Underweight / normal weight	227/783 (29.0%)	1.23 [1.00; 1.51]	0.050
Concomitant medication	No	418/1493 (28.0%)	Yes	59/294 (20.1%)	0.65 [0.48; 0.88]	0.005
Education	>= higher school certificate	332/1271 (26.1%)	<= secondary school certificate	167/604 (27.7%)	1.08 [0.87; 1.34]	0.484
Salary	>= 3000€	241/811 (29.7%)	< 3000€	256/1053 (24.3%)	0.76 [0.62; 0.93]	0.009
Sex	Female	130/598 (21.7%)	Male	370/1281 (28.9%)	1.46 [1.16; 1.84]	0.001
HF reducing medication	No	457/1680 (27.2%)	Yes	43/199 (21.6%)	0.74 [0.52; 1.05]	0.092
Buying motive	Other Aspects	245/815 (30.1%)	Health Improvement	233/675 (34.5%)	1.23 [0.99; 1.53]	0.067
Comorbidities	No	288/912 (31.6%)	Yes	209/940 (22.2%)	0.62 [0.50; 0.76]	<0.001
Physical disabilities/disorders	No	56/186 (30.1%)	Yes	444/1689 (26.3%)	0.83 [0.59; 1.15]	0.264
Primary bike use*	Every day use	139/508 (27.4%)	Leisure	140/472 (29.7%)	1.12 [0.85; 1.48]	0.517
			Commuting	164/429 (38.2%)	1.64 [1.25; 2.16]	0.087
			Sport	36/83 (43.4%)	2.03 [1.26; 3.27]	0.028
			Other	3/13 (23.1%)	0.80 [0.22; 2.94]	0.400
Smoking status	No	469/1730 (27.1%)	Yes	31/142 (21.8%)	0.75 [0.50; 1.13]	0.173
Sport points (physical activity questionnaire)	>= 43	275/939 (29.3%)	< 43	224/933 (24.0%)	0.76 [0.62; 0.94]	0.009
Study group	Conventional cycling	220/629 (35.0%)	E-bike	280/1250 (22.4%)	0.54 [0.43; 0.66]	<0.001

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable).
* type III F-test was performed for primary bike use (p=0.0008)

Table S2. Multiple binary logistic regression model for reaching the physical activity target

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	0.56 [0.43; 0.72]	<0.001	0.52 [0.41; 0.66]	<0.001
Age (>=53 years)	<53 years	0.60 [0.47; 0.78]	0.001	0.58 [0.45; 0.74]	<0.001
BMI (underweight / normal weight)	Overweight / obesity	1.03 [0.80; 1.31]	0.835		
Sex (female)	Male	1.34 [1.02; 1.74]	0.033	1.37 [1.06; 1.77]	0.017
Salary (>= 3000€)	< 3000€	0.89 [0.71; 1.13]	0.344		
HF reducing medication (no)	Yes	0.90 [0.59; 1.36]	0.618		
Comorbidities (no)	Yes	0.65 [0.51; 0.83]	<0.001	0.64 [0.51; 0.80]	<0.001
Buying motive (pragmatic)	Health	1.22 [0.96; 1.55]	0.100		
Sport points in the physical activity questionnaire (>=43 pts)	< 43 pts	0.81 [0.64; 1.03]	0.083		
Primary bike use** (everyday use)	Leisure time	1.27 [0.94; 1.73]	0.125	1.26 [0.93; 1.70]	0.129
	Commuting	1.93 [1.43; 2.62]	<0.001	1.91 [1.42; 2.59]	<0.001
	Sports-related	2.18 [1.32; 3.62]	0.003	2.26 [1.37; 3.73]	0.001
	Other	0.94 [0.24; 3.62]	0.928	0.94 [0.24; 3.63]	0.932

Hosmer-Lemeshow test for the final model): $\chi^2(8) = 4.43$, $p = 0.816$ * multiple binary logistic regression to determine prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.
** type III F-test was performed for primary bike use and was statistically significant before and after backward selection

($p<.001$)

Sensitivity analysis for MVPA cycling activities according to the 2020 WHO guidelines for physical activity (PA)

In addition to our primary analysis relating to the "2010 WHO global recommendations on physical activity for health" [1] which stated that moderate- and vigorous-intensity activity (MVPA) should be performed in bouts of at least 10 minutes duration, we conducted a sensitivity analysis according to the recently published "2020 WHO guidelines on physical activity and sedentary behavior" [2].

In contrast to the WHO recommendation published in 2010, the 2020 WHO guideline states that now MVPA bouts of any duration count towards the calculation of MVPA minutes per week. Therefore, we reanalyzed our data and counted any cycling activity if the heart rate was above the lower individual threshold of the respective intensity level (moderate or vigorous), and present this as sensitivity analysis for the primary outcomes.

Cycling at MVPA per week, and reaching the target of cycling 150 min at MVPA per week (according to the 2020 WHO guidelines for PA)

Time spent at MVPA during cycling per week was higher for the bicycle group (bicycle: 166.4 ± 195.6 min/week; e-bike: 105.3 ± 139.0 min/week) with a mean difference between groups of 61.2 min/week [CI95% 45.8; 76.5], p<0.001. A higher proportion of conventional bicycle users (41.2%) cycled 150 min or more at MVPA per week when compared to e-bike users (27.2%) (p<0.001).

Univariate analysis and prognostic factors for reaching the physical activity target (according to the 2020 WHO guidelines for PA)

Table S3. Univariate binary logistic regression for reaching the physical activity target

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Age	>= 53 years	341/979 (34.8%)	<53 years	258/900 (28.7%)	0.75 [0.62; 0.91]	0.004
Children	>1	129/380 (34.0%)	0-1	461/1475 (31.3%)	0.88 [0.70; 1.12]	0.315
BMI	Overweight / obesity	328/1091 (30.1%)	Underweight / normal weight	270/783 (34.5%)	1.22 [1.01; 1.49]	0.043
Concomitant medication	No	494/1493 (33.1%)	Yes	71/294 (24.2%)	0.64 [0.48; 0.86]	0.003
Education	>= higher school certificate	413/1271 (32.5%)	<= secondary school certificate	185/604 (30.6%)	0.92 [0.74; 1.13]	0.418
Salary	>= 3000€	276/811 (34.0%)	< 3000€	318/1053 (30.2%)	0.84 [0.69; 1.02]	0.079
Sex	Female	164/598 (27.4%)	Male	435/1281 (34.0%)	1.36 [1.10; 1.68]	0.005
HF reducing medication	No	547/1680 (32.6%)	Yes	52/199 (26.1%)	0.73 [0.53; 1.02]	0.067
Buying motive	Other Aspects	300/815 (36.8%)	Health Improvement	271/675 (40.2%)	1.15 [0.93; 1.42]	0.187
Comorbidities	No	337/912 (37.0%)	Yes	258/940 (27.5%)	0.65 [0.53; 0.79]	<.001
Physical disabilities/disorders	No	58/186 (31.2%)	Yes	541/1689 (32.0%)	1.04 [0.75; 1.44]	0.815
Primary bike use*	Every day use	183/508 (36.0%)	Leisure	161/472 (34.1%)	0.92 [0.71; 1.20]	0.089
			Commuting	191/429 (44.5%)	1.43 [1.10; 1.85]	0.200
			Sport	39/83 (47.0%)	1.57 [0.99; 2.51]	0.175
			Other	5/13 (38.5%)	1.11 [0.36; 3.44]	0.894
Smoking status	No	562/1730 (32.5%)	Yes	37/142 (26.1%)	0.73 [0.50; 1.08]	0.116
Sport points (activity questionnaire)	>= 43	324/939 (34.5%)	< 43	273/933 (29.3%)	0.79 [0.65; 0.95]	0.015
Study group	Conventional cycling	259/629 (41.2%)	E-bike	340/1250 (27.2%)	0.53 [0.44; 0.65]	<.001

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). * type III F-test was performed for primary bike use (p=0.007)

Table S4. Multiple binary logistic regression model for reaching the physical activity target

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	0.54 [0.42; 0.69]	<0.001	0.51 [0.40; 0.65]	<0.001
Age (>=53 years)	<53 years	0.53 [0.42; 0.68]	<0.001	0.52 [0.41; 0.67]	<0.001
BMI (underweight / normal weight)	Overweight / obesity	1.00 [0.79; 1.27]	0.968		
Sex (female)	Male	1.30 [1.01; 1.67]	0.044	1.30 [1.02; 1.66]	0.035
Salary (>= 3000€)	< 3000€	0.97 [0.78; 1.22]	0.818		
HF reducing medication (no)	Yes	0.84 [0.57; 1.25]	0.400		
Comorbidities (no)	Yes	0.68 [0.54; 0.86]	0.001	0.67 [0.53; 0.83]	<0.001
Buying motive (pragmatic)	Health	1.15 [0.92; 1.45]	0.219		
Sport points (physical activity questionnaire) (>=43 pts)	< 43 pts	0.88 [0.69; 1.10]	0.261		
Primary bike use** (every day use)	Leisure time	1.00 [0.75; 1.34]	0.974	1.00 [0.75; 1.33]	0.984
	Commuting	1.71 [1.28; 2.29]	<0.001	1.70 [1.27; 2.27]	<0.001
	Sports-related	1.75 [1.06; 2.88]	0.027	1.79 [1.10; 2.93]	0.020
	Other	0.92 [0.26; 3.22]	0.900	0.94 [0.27; 3.27]	0.922

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(8) = 7.72$, $p = 0.461$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the success rate of reaching the physical activity target of cycling 150 min at MVPA (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with p<0.05 remained in the "Final model" as reported above.

Univariate and multiple analysis for prognostic factors for having at least one road traffic accident or near-accident

First, univariate binary logistic regression models were used to identify potential prognostic factors and confounders (p<0.1) influencing the success rate of having at least one road traffic accident (Table S5) or near-accident (Table S7), respectively. Then, potential prognostic factors were included in multiple binary logistic regression analysis and backward selection was used to drop independent variables with the highest p-value until only covariates and factors remained in the model that were significantly associated (p<0.05) with having at least one road traffic accident (Table S6) or near-accident (Table S8), respectively.

Table S5. Univariate binary logistic regression for having at least one traffic accident

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi^2-Test)
Age	>= 53 years	47/979 (4.8%)	<53 years	55/900 (6.1%)	1.29 [0.86; 1.93]	0.212
Sex	female	32/598 (5.4%)	male	70/1281 (5.5%)	1.02 [0.67; 1.57]	0.919
Overall cycling time	<= 110 min/wk	35/941 (3.7%)	> 110 min/wk	67/938 (7.1%)	1.99 [1.31; 3.03]	0.001
Cycling frequency	<= 3 trips/wk	37/924 (4.0%)	> 3 trips/wk	65/955 (6.8%)	1.75 [1.16; 2.65]	0.008
Study group	Conventional cycling	26/629 (4.1%)	E-bike	76/1250 (6.1%)	1.50 [0.95; 2.37]	0.080

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the probability of having at least one accident (dependent variable).

Table S6. Multiple binary logistic regression model for having at least one traffic accident

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi²-Test)	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Study Group (cycling)	E-bike	1.63 [1.02; 2.58]	0.039	1.59 [1.00; 2.51]	0.048
Overall cycling time (<= 110 min/wk)	> 110 min/wk	1.74 [0.96; 3.17]	0.069	2.05 [1.35; 3.13]	0.001
Cycling frequency (<= 3 trips/wk)	> 3 trips/wk	1.26 [0.69; 2.28]	0.451		

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(2) = 1.66$, $p = 0.437$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the probability of having at least one accident (dependent variable). After univariate analyses to detect covariables that were significantly associated with the independent variable (here included in the "Full model"), multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.

Table S7. Univariate binary logistic regression for having at least one near-accident

Variable	Reference group	Estimate	Effect group	Estimate	Odds Ratio [CI 95%]	p-value (Chi²-Test)
Age	>= 53 years	57/979 (5.8%)	<53 years	77/900 (8.6%)	1.51 [1.06; 2.16]	0.022
Sex	female	33/598 (5.5%)	male	101/1281 (7.9%)	1.47 [0.98; 2.2]	0.065
Overall cycling time	<= 110 min/wk	38/941 (4.0%)	> 110 min/wk	96/938 (10.2%)	2.71 [1.84; 3.99]	<0.001
Cycling frequency	<= 3 trips/wk	35/924 (3.8%)	> 3 trips/wk	99/955 (10.4%)	2.94 [1.98; 4.37]	<0.001
Study group	Conventional cycling	48/629 (7.6%)	E-bike	86/1250 (6.9%)	0.89 [0.62; 1.29]	0.550

Univariate binary logistic regression to identify potential prognostic factors and confounders influencing the probability of having at least one near-accident (dependent variable).

Table S8. Multiple binary logistic regression model for having at least one near-accident

Independent variable* (reference group)	Estimate	Full Model		Final Model (after stepwise backward selection)	
		Odds Ratio [CI 95%]	p-value (Chi^2-Test)	Odds Ratio [CI 95%]	p-value (Chi^2-Test)
Study Group (cycling)	E-bike	1.12 [0.77; 1.64]	0.548		
Overall cycling time (<= 110 min/wk)	> 110 min/wk	1.71 [1.00; 2.92]	0.051	1.74 [1.02; 2.98]	0.043
Cycling frequency (<= 3 trips/wk)	> 3 trips/wk	2.02 [1.16; 3.51]	0.013	1.97 [1.14; 3.41]	0.015
Sex (female)	Male	1.45 [0.96; 2.18]	0.078		
Age (>=53 years)	<53 years	1.61 [1.12; 2.33]	0.010	1.57 [1.10; 2.25]	0.014

Goodness-of-fit (Hosmer-Lemeshow test for the final model): $\chi^2(4) = 1.689$, $p = 0.793$, * multiple binary logistic regression to determine prognostic factors and confounders influencing the probability of having at least one near-accident (dependent variable). After univariate analyses, multiple regression analysis with backward selection was conducted, until only covariables with $p<0.05$ remained in the "Final model" as reported above.

References

1. World Health Organization. Global Recommendations on Physical Activity for Health 2010 [Available from: https://www.who.int/dietphysicalactivity/global-PA-recs-2010.pdf accessed 12 Feb 2021.
2. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine* 2020;54:1451-62.

BMJ OPEN SPORT & EXERCISE MEDICINE

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Evidence type: Observational
Subjects: People

E-bikes not likely to help users reach moderate-vigorous physical activity targets

Riders tend to take fewer and less physically demanding trips than conventional cyclists
But e-bikes may persuade older people to take to two wheels who wouldn't otherwise cycle

E-bikes aren't likely to help users reach weekly moderate to vigorous physical activity targets, because riders tend to take fewer and less physically demanding trips than conventional cyclists, suggests research published in the open access journal ***BMJ Open Sport & Exercise Medicine.***

But e-bikes may persuade older and/or overweight people to take to two wheels who wouldn't otherwise consider using a bike, suggest the researchers.

E-bikes have become increasingly popular in recent years, with around 3.4 million sold in European Union countries in 2019, compared with only 98,000 in 2006.

This number is expected to increase further to 62 million by 2030. And a similarly rapid rise in popularity is anticipated in Asia and the USA.

It's not entirely clear whether e-bikes help users meet physical activity guidelines and whether they might also boost the rate of cycling accidents.

The researchers therefore compared recommended weekly targets of 150 minutes moderate-intense, or 75 minutes of vigorous-intense, physical activity (MVPA) and accident rates in 1250 e-bikers and 629 conventional cyclists from across Germany.

The volunteers provided information on health related quality of life, daily physical activity, and health issues, as well as details of any cycling accidents.

They were asked to record the riding time, distance travelled, and heart rate for every cycle ride over a period of 4 weeks, using a smartwatch activity tracker. Accident rates were monitored over a period of 12 months.

The e-bikers tended to be older, weigh more, have more underlying health conditions, and to do less exercise but more leisure time physical activity than the conventional cyclists.

E-bikers did an average of almost 70 fewer minutes of MVPA than conventional cyclists, who clocked up 150+ minutes more MVPA on their bikes.

Conventional cyclists also took more weekly trips, on average, than the e-bikers: around 6 *vs* around 4.

The overall time spent on a bike was also nearly 25 minutes longer, on average, among the conventional cyclists, although e-bikers took longer trips, clocking up an average of 6.5 extra minutes.

Cyclists' average heart rates were also higher, suggesting a greater level of exertion: 119 beats per minute *vs* 111 beats per minute among the e-bikers.

Age, sex, underlying conditions, and reported use of a bike for sport and commuting were significant predictive factors for reaching weekly recommended physical activity targets. E-bikers were around half as likely as conventional cyclists to reach these targets.

Overall, 109 accidents and 157 near accidents occurred during the 12-month monitoring period. After accounting for potentially influential factors, use of an e-bike and overall time spent on a bike, predicted road traffic accident risk, with e-bikers 63% more likely to have a traffic accident than conventional cyclists.

The most commonly cited reason for buying either type of bike was physical fitness, but e-bikers were twice as likely to cite convenience (ease of cycling) as the conventional cyclists. Protecting the environment or saving money were scarcely mentioned.

"The participant characteristics of our cohort suggest that e-biking is of interest, particularly for those who will benefit the most for health-related fitness—namely, older users, overweight and obese individuals, or those with health related limitations and fewer exercise activities," write the researchers.

This is an observational study, and the researchers acknowledge that heart rate assessment wasn't as accurate as an ECG trace would have been.

But their findings back up those of previous studies showing that "e-biking provides the option to continue cycling despite physical limitations, and has the potential to maintain physical activity and fitness," they add.

"Further research on users' motives and possible replacement of other transport modes is necessary to shed light on whether e-bikes, as an active form of electromobility, could feasibly provide a relevant contribution to mitigating traffic congestion and air pollution, and promote active living," they conclude.