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Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities

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ABSTRACT

Physical activity has been widely associated with beneficial health effects. The use of electric-assist bicycles (e-bikes) can lead to increased or decreased physical activity, depending on the transport mode substituted.

This study aimed to compare physical activity levels of e-bikers and conventional bicycle users (cyclists) as well as across e-bike user groups based on the transport mode substituted by e-bike. Physical activity, transport and user related parameters were analysed. Data from the longitudinal on-line survey of the PASTA project were used. The survey recruited over 10,000 participants in seven European cities.

Physical activity levels, measured in Metabolic Equivalent Task minutes per week (MET min/wk), were similar among e-bikers and cyclists (4463 vs. 4085). E-bikers reported significantly longer trip distances for both e-bike (9.4 km) and bicycle trips (8.4 km) compared to cyclists for bicycle trips (4.8 km), as well as longer daily travel distances for e-bike than cyclists for bicycle (8.0 vs. 5.3 km per person, per day, respectively). Travel-related activities of e-bikers who switched from cycling decreased by around 200 MET min/wk., while those switching from private motorized vehicle and public transport gained around 550 and 800 MET min/wk. respectively.

Therefore, this data suggests that e-bike use leads to substantial increases in physical activity in e-bikers switching from private motorized vehicle and public transport, while net losses in physical activity in e-bikers switching from cycling were much less due to increases in overall travel distance.

Abbreviations: E-bike, electric-assist bicycles; MET, Metabolic Equivalent Task; BMI, Body Mass Index; HFCE, household final consumption expenditure; PASTA, Physical Activity through Sustainable Transport Approaches; GPAQ, Global Physical Activity Questionnaire; API, Application Programming Interface; CI, confidence interval; N, sample size.

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1. Introduction

Electric-assist bicycles (e-bikes) can be defined as bicycles that "are similar in geometry to human-powered bicycles but have a small electric motor that provides pedal assistance and allows riders to accelerate, climb hills, and overcome wind resistance more easily than manually powered bikes" (MacArthur and Kobel, 2014). The level of electric support depends on the category of e-bike, namely pedelecs and speed-pedelecs. Power can range from up to 250 W in pedelecs to up to 4000 W in speed-pedelecs, translating into maximum speeds of up to 25 km/h and up to 45 km/h, respectively. Human-pedalling is required for pedelecs, and although technically optional in speed-pedelecs (Clark et al., 2016; EU Parliament & Council) the majority of European speed-pedelecs require it. Sales and uptake of e-bikes have rapidly increased over the past decade worldwide, including in Europe (Fishman and Cherry, 2016; Weiss et al., 2015). The uptake of e-bikes implies at least in part a shift from other transport modes, mainly private motorized vehicles, public transport and conventional bicycles (hereafter referred to as bicycle). Shifts from walking may be assumed to play a negligible role because walking trips are typically much shorter than e-bike trips. In addition, the uptake of e-bikes may meet latent demand, meaning the demand was induced by the option to travel by e-bike.

Conventional bicycling (hereafter referred to as cycling) produces health benefits through physical activity (Götschi et al., 2016; Kelly et al., 2014), which from a public health perspective largely outweigh risks of exposure to air pollution and traffic crashes (Mueller et al., 2015). Analogously, e-biking being an active mode, positive health impacts from physical activity can be expected, but net impacts may differ from conventional bicycling due to lower intensity of activity as well as potentially different travel patterns as shown below.

Few studies have associated e-biking directly with health outcomes. Commuting by e-bike has been associated with health benefits in terms of several physiological parameters, e.g. body mass index, fixed blood lactate concentration or power output (Dons et al., 2018; de Geus et al., 2013; Peterman et al., 2016). Regarding physical activity, e-biking requires less physical effort than cycling due to the electric-motor support (Sperlich et al., 2012). Previous research showed that body energy consumption when pedalling while e-biking to be 24% lower than on bicycles (Langford et al., 2017), while others found that this value can range from 15% to 25% depending on the level of assistance (Otero et al., 2018). Using an e-bike requires moderate to vigorous intensity physical activity, depending on topography (Langford et al., 2017). Further, e-biking has been shown to reduce travel times by 35% on hilly routes and by 15% on flat routes, resulting in shorter durations of activity (Berntsen et al., 2017). It has also been suggested that for those people who start using e-bikes other physical activities are not significantly affected; i.e. there may not be an activity substitution effect (Sundfør and Fyhri, 2017; Van Cauwenberg et al., 2018; Höchsmann et al., 2018).

There is a growing body of international literature that describes travel mode substitution and travel patterns of e-bike users including in China (Fishman and Cherry, 2016; Cherry and Cervero, 2007; Montgomery, 2010; Weinert et al., 2007), the United States (MacArthur and Kobel, 2014; Dill and Rose, 2012; Popovich et al., 2014) and Australia (Johnson and Rose, 2013), as previously reviewed (Kroesen, 2017). Since this analysis used European data and travel patterns are influenced by local circumstances, we focus on reviewing European studies.

In a review of 18 European studies (including grey literature) (Cairns et al., 2017) it was found that depending on the study, average weekly mileage by e-bike ranged from 15 km to >70 km; average commute trip length ranged from 9.8 to 17 km; the share of e-bike trips substituting car trips ranged from 16% to 76%; and average speed of e-bikes was comparable to urban public transport. These findings are consistent with the below presented additional scientific literature. In Denmark a survey among >400 e-bikers showed that they substituted conventional bicycle trips (64%), car trips (49%) and bus trips (48%) (multiple choice) (Haustein and Møller, 2016). In the United Kingdom a trial over 6–8 weeks among 80 employees found that 43% of these participants self-reported less car use as driver, 37% reported less walking, 33% reported less bus trips and 25% reported less conventional cycling during the trial. Car mileage was reduced by 20% (Cairns et al., 2017). A qualitative study in the Netherlands and United Kingdom obtained a similar result using 22 semi-structured interviews: around half of the e-bikers reduced conventional bicycle use and car use, 36% reduced public transport use and 14% walking. In contrast, around 9% of e-bikers increased conventional bicycle use and car use and walking (Jones et al., 2016). In the Netherlands a study compared e-bike owners with non-owners using data from the Dutch Mobility Survey. E-bike users reported lower conventional bicycle, public transport and car distance travelled (66%, 64% and 28% respectively in a bivariate analysis) (Kroesen, 2017). Changes in transport mode choice after the uptake of e-bikes might be sustained over time as found in a test trial in Switzerland (Moser et al., 2018).

Furthermore, it has been found that e-bike trips are faster than conventional bicycle trips when comparing random routes (Otero et al., 2018; Petzoldt et al., 2017; Schleinitz et al., 2017) and the same routes (Sperlich et al., 2012; Langford et al., 2017; Berntsen et al., 2017), in particular when sharing road with motorized traffic (Langford et al., 2015).

The current study aims to increase understanding of the implications for physical activity levels with the uptake of e-bike use in Europe based on reported travel patterns. Studies that investigate physiological effects of e-biking focus normally on contrasts in intensity of activity (de Geus et al., 2013; Peterman et al., 2016; Langford et al., 2017; Berntsen et al., 2017). From a public health perspective, more relevant are the contrasts in net volume of physical activity per week, which additionally depends on the previously used transport mode, and changes in travel patterns. Therefore, this paper explores e-bike users' travel patterns and resulting weekly physical activity levels in comparison to cyclists and non-cyclists and puts a particular focus on previous travel modes substituted by e-biking.

2. Data and methods

This study used data from the longitudinal, online survey conducted as part of the European research project Physical Activity through Sustainable Transport Approaches (PASTA) (Dons et al., 2015; Gerike et al., 2016). PASTA aimed to strengthen the understanding of determinants of active mobility (Götschi et al., 2017) as well as its health impacts (Mueller et al., 2018) by integrating approaches from transport and health research. The survey took place from November 2014 to January 2017 in seven European cities: Antwerp (Belgium), Barcelona (Spain), London (United Kingdom), Örebro (Sweden), Rome (Italy), Vienna (Austria) and Zurich (Switzerland). Survey participants were recruited opportunistically on a rolling basis, applying a diverse set of approaches but following a common sampling strategy across cities (Gaupp-Berghausen and Raser, 2017). Active transport modes were intentionally oversampled to have sufficiently large sample sizes for different transport modes in each of the cities. Participants from the age of 18 years (16 years in Zurich) were allowed to participate (Dons et al., 2015; Raser et al., 2018).

Survey participants filled out an extensive baseline questionnaire followed by follow-up questionnaires approximately every two weeks. The baseline questionnaire included questions on socio-economic and psychological background of participants, their travel behaviour including bicycle types used and a one-day travel diary, their physical activity level, as well as geo-location of their home and work or place of education. Short follow-up questionnaires included brief questions on travel behaviour, physical activity and traffic crashes, while every third follow-up questionnaire included longer assessments of physical activity and a one day travel diary (Dons et al., 2015; Gerike et al., 2016; Raser et al., 2018). Survey participants were incentivized to complete the questionnaires through lotteries. The chances of winning a prize increased with the number of completed questionnaires. These lotteries were applied in six out of the seven cities. In Örebro it was not allowed by the Swedish law. More details on the recruitment strategy has been published elsewhere (Gaupp-Berghausen et al., 2019).

The presented analysis takes two perspectives: First, participant characteristics, travel behaviour and resulting physical activity are compared between three groups: e-bikers, cyclists and non-cyclists. Secondly, within e-bikers, comparisons are made across subgroups based on main travel mode substituted by e-bike, such as car, public transport, bicycle or multiple modes. The distinction of e-bikers vs. cyclists was based on the following question at the baseline: “What type of bicycle do you use?”. Respondents stating that they used an e-bike were categorized as e-bikers, independent of whether they also used a conventional bicycle. Using this classification around the half of e-bikers only use e-bike while the other half use additionally a different type of bicycle. Users who reported any use of non-electric bicycle (including city bike, mountain bike or bike-sharing) but not e-bike were categorized as cyclists, those who did not report any bicycle use, as non-cyclists. Bike-sharing schemes in the studied cities were non-electric during the survey period. Therefore, it was assumed that the e-bikes of e-bikers were personally owned and not part of a bike-sharing system. The assignment of the substituted mode group was based on the following question at the baseline questionnaire: “Thinking about the journeys that you use your electric bike for now, what method of travel did you use before using an electric bike?”. This question was asked only once in the survey and persistence of the decision to switch to e-bike was not assessed.

The total sample of survey participants was characterized among groups regarding background aspects such as city, age, sex, income, education level, car access and body mass index (BMI, weight in kilograms divided by square of height in meters). To facilitate comparison across groups, income categories were converted to a continuous scale by replacing the seven original income ranges with the midpoint of each range. In addition, to avoid comparability issues across cities income data was adjusted dividing by a national price level index for household final consumption expenditure (HFCE) (EUROSTAT, 2016). Furthermore, some e-bike specific background aspects such as transport mode substitution, motivation for e-biking, safety perception and helmet use were analysed. Both general and e-bike specific background aspects of the sample of participants were based on data from the baseline questionnaire.

Travel behaviour was assessed using the following indicators: a) travel frequency in terms of days per month and trips per day, b) travel duration and c) travel distance, all stratified by transport mode. Travel frequency in terms of day per month was captured in the baseline questionnaire using a mode frequency table, including separate entries for cycling and e-biking. Categorical travel frequency data was converted into an average number of days per month. Participants further reported trip durations in a one-day travel diary at baseline and as part of every third follow-up. Travel frequency in terms of trips per day was derived using the travel diary. Trip duration was estimated using start and end time of each reported trip and assigning this total trip duration to the main transport mode involved (i.e. transit trip duration includes some walking). Additionally, weekly durations riding e-bike or conventional bicycle were captured using an adapted version of the Global Physical Activity Questionnaire (GPAQ) (Cleland et al., 2014; WHO, 2014) at baseline and during follow-ups and converted to daily travel durations. In contrast to the original version of the GPAQ, walking, cycling and e-biking durations were captured separately. Trip distances were derived based on origin and destination locations reported through a map widget in the travel diary, which were afterwards used to obtain fastest routes using the Google Maps Application Programming Interface (API) (Google). Trip distance was derived by selecting the fastest route returned by the Google Maps API (Raser et al., 2018). Geo-locations of origins and destinations were only available at the trip level. Distances for multimodal trips were assigned to the main mode using the following hierarchy: public transport, car, e-bike, bicycle, walking (Raser et al., 2018). Further, average trip distance and duration as well as average daily travel distance and duration were estimated using data from the travel diaries. Average trip distance and duration were calculated as the mean of all trips from baseline and follow-up questionnaires. Average daily travel distance and duration were calculated as the mean of daily trips across follow-ups within participant, and then averaged across all participants.

Physical activity was assessed using the following indicators: a) MET minutes per week based on GPAQ and b) the *single-item physical activity measure (*Hartmann, 2017*;* Milton et al., 2011*)*. The GPAQ was used at baseline and during every third follow-up to capture duration and intensity of physical activities in the domains labour, transport (see above) and leisure. Standard values of intensity for each activity, measured in Metabolic Equivalents of Task (METs) were applied to calculate physical activity (measured in MET minutes per week) (WHO, 2014; Laeremans et al., 2017). Overall physical activity, as well as transport related physical activity were calculated assuming 4 METs for moderate and 8 METs for vigorous intensity physical activity, 6.8 METs for cycling, 4 METs for walking, and 5 METs for e-biking (Peterman et al., 2016; Sperlich et al., 2012). To estimate physical activity before using e-bike, the following intensities for substituted non-active transport modes were assumed: 2.5 METs for car (car-driving) and 1.3 METs for public transport use (excluding access trips, egress trips and transfer) (Ainsworth et al). For “other or multiple mode” substitution no physical activity before using e-bike was estimated since the proportion of each substituted mode was unknown. The single-item physical activity measure asked participants a single question: “In a typical week, on how many days do you do a total of 30 min or more of physical activity, which is enough to raise your breathing rate? This may include sport, exercise, and brisk walking or cycling for recreation or to get to and from places, but should not include housework or physical activity that may be part of your job” (Milton et al., 2011) (only baseline questionnaire was considered).

In total 10,722 persons participated in the survey and 87,094 questionnaires (including baseline and follow-ups) were collected. The number of participants in follow-up questionnaires decreased over time from around 6800 in the first one, to <1000 from the 25th one. Travel diaries were provided by 7809 participants recording 76,986 trips. As a result of data cleaning the final data set included 9335 persons, 76,283 questionnaires and 40,553 trips. Additionally GPAQ data were recoded according to WHO guidelines (WHO, 2014) and following the work of Laeremans et al. (Laeremans et al., 2017). Further details of the data cleaning and recoding can be found in the Supplementary materials.

Statistical analysis was conducted in open-source software R (R Core Team, 2017). Normal distribution for studied variables was assumed based on inspection of data. Comparisons of means were based on ANOVA for continuous variables and Chi-square test for categorical and binomial variables, and corresponding confidence intervals and p-values were calculated. Confidence intervals were calculated applying the classic method for continuous variables, Wilson method for binomial variables and Sison & Glaz method for categorical variables and using the DescTool R package (Signorell et al., 2018).

3. Results

Table 1 shows characteristics of the survey participants by bicycle user type. 365 persons stated that they use e-bikes. Only two cities collected >100 e-bike users: 112 in Antwerp and 107 in Zurich.

E-bikers were on average significantly older than cyclists (48.1 vs. 41.4 years old), had higher car access (68% vs. 51%) and had higher BMI (24.8 vs. 23.8). No substantial differences were found in terms of sex, level of education and income when comparing e-bikers with cyclists. Fewer men than women were neither cyclists nor e-bikers.

Table 2 shows indicators of travel behaviour. E-bikers use their e-bikes with similar frequency in terms days of use per month as cyclists use bicycles (14.5 vs. 14.0 days per month), but had significantly lower frequencies of public transport use, cycling and walking, as compared to cyclists (7.7, 7.9 and 16.3 days per month vs. 10.4, 14.0 and 18.9, respectively). Travel frequency in terms of average number of trips per day using the three above mentioned transport modes was also significantly lower among e-bikers than among cyclists (0.4, 0.3, 0.5 trips per day vs. 0.7, 1.1. and 0.7, respectively), being the number of e-bike trips per day lower among e-

Table 1
Survey participant characteristics by bicycle user type.

Variable	E-bikers Value (CI)	N	Cyclists Value (CI)	N	Non-cyclists Value (CI)	N	All Value (CI)	N	P-value
City									
Antwerp	31% (25%; 36%)	112	17% (16%; 18%)	1197	1% (0%; 4%)	21	14% (13%; 15%)	1330	< 0.001
Barcelona	5% (0%; 11%)	20	14% (13%; 15%)	987	25% (23%; 28%)	444	16% (15%; 17%)	1451	
London	1% (0%; 7%)	5	11% (10%; 12%)	775	28% (25%; 30%)	486	14% (13%; 15%)	1266	
Örebro	5% (0%; 10%)	18	17% (15%; 18%)	1191	3% (0%; 5%)	50	13% (13%; 14%)	1259	
Rome	17% (12%; 23%)	63	14% (13%; 15%)	1011	27% (25%; 30%)	480	17% (16%; 18%)	1554	
Vienna	11% (6%; 16%)	40	16% (15%; 17%)	1131	7% (5%; 10%)	125	14% (13%; 15%)	1296	
Zurich	29% (24%; 35%)	107	13% (12%; 14%)	920	9% (6%; 11%)	152	13% (12%; 14%)	1179	
Total	100%	365	100%	7212	100%	1758	100%	9335	
Sex									
Male	51% (46%; 57%)	187	48% (47%; 49%)	3476	38% (36%; 40%)	668	46% (45%; 47%)	4331	< 0.001
Female	49% (44%; 54%)	178	52% (51%; 53%)	3736	62% (60%; 64%)	1090	54% (53%; 55%)	5004	
Total	100%	365	100%	7212	100%	1758	100%	9335	
Age									
(Mean)	48.1 (47.0; 49.3)	365	41.4 (41.1; 41.7)	7211	42.0 (41.4; 42.7)	1757	41.8 (41.5; 42.0)	9333	< 0.001
Level of education									
University or similar	70% (65%; 75%)	212	74% (73%; 75%)	4382	67% (65%; 70%)	890	73% (72%; 74%)	5484	< 0.001
Lower degree	30% (26%; 36%)	93	26% (25%; 27%)	1535	33% (30%; 35%)	434	27% (26%; 28%)	2062	
Total	100%	305	100%	5917	100%	1324	100%	7546	
HFCE-adjusted income (in thousand EUR per year)									
(Mean)	76.0 (70.3; 81.7)	365	77.3 (75.9; 78.7)	7212	96.9 (93.7; 100.2)	1758	81.0 (79.7; 82.3)	9335	< 0.001
Car/van access									
Always	68% (63%; 73%)	247	51% (50%; 52%)	3684	44% (42%; 47%)	779	50% (49%; 52%)	4710	< 0.001
Sometimes	24% (20%; 29%)	89	28% (27%; 29%)	2008	20% (18%; 23%)	358	26% (25%; 27%)	2455	
Never	8% (3%; 13%)	29	21% (20%; 22%)	1520	35% (33%; 38%)	621	23% (22%; 24%)	2170	
Total	100%	365	100%	7212	100%	1758	100%	9335	
Body Mass Index									
(Mean)	24.8 (24.4; 25.3)	306	23.8 (23.7; 23.9)	5949	24.4 (24.1; 24.6)	1336	23.9 (23.8; 24.0)	7591	< 0.001

N = sample size. CI = confidence interval. HFCE = national price level index for household final consumption expenditure. Column-wise percentages. P-value of the first three groups was calculated using ANOVA test for continuous variables and Chi-square test for categorical and binomial variables.

bikers than the number of bicycle trips per day among cyclists. The number of trips per day using a car was similar across e-bikers, cyclists and non-cyclist. For average trip duration, average trip distance and daily travel distance, the following differences between e-bikers and cyclists could be observed. Average e-bike and bicycle trip duration among e-bikers (35.0 and 41.9 min respectively) was significantly higher than bicycle trip duration among cyclists (25.6 min). In terms of average trip distance similar significant differences were found when comparing e-bikers (9.4 km for e-bike and 8.4 km for bicycle trips) with cyclists (4.8 km for bicycle trips). Average daily travel duration was similar for e-biking among e-bikers and cycling among cyclists (32.2 vs. 30.3 min), but e-bikers, in addition, reported 13.4 min of cycling. Moreover, e-bikers reported significant longer daily distances travelled by e-bike than cyclists by bicycle (8.0 vs. 5.3 km per person per day) and e-bikers additionally reported 2.5 km per day by bicycle.

Table 3 shows physical activity based on activity durations from GPAQ, and single-item physical activity measure. Overall physical activity is higher among e-bikers than among cyclists (4463 vs. 4085 MET minutes per week), although the difference was small (< 10%) and not significant (p-value among the three bicycle type groups is below 0.001 but confidence interval of e-bikers and cyclists overlap). Both e-bikers and cyclists were significantly more active than non-cyclists. The largest difference between e-bikers and cyclists was reported in terms of work-related activity (physical activity done at work), while travel-related physical activity was similar. Physical activity from active travel modes was almost the same in e-bikers and cyclists (1735 vs. 1656 MET min/wk., respectively). It should be noted that e-bikers, in addition to over 800 MET minutes per week from e-biking, reported a substantial amount of cycling (471 MET min/wk). Cyclists on the other hand "only" reported about 1000MET min/wk. from cycling. Walking levels were comparable in both groups, but substantially lower compared to non-cyclists. According to the single-item physical activity measure (in days in a week with at least 30 min of physical activity) e-bikers and cyclists were equally active (approximately 4 days/wk), and significantly more active than non-cyclists (approximately 3 days/wk).

Table 4 shows the answer to e-bike specific questions of the survey. With regards to previous travel mode substituted by e-bike, 25% exclusively substituted private motorized vehicle trips (car or motorbike), 23% exclusively substituted non-electric bicycle trips, and 15% exclusively substituted public transport trips. Other substituted modes, or combinations of modes, were reported by < 10% of e-bike users and induced travel demand (no transport mode substituted) reached 4%. The main motivations of e-bikers to start using e-bikes were reduced physical effort (26%), to save time with faster trips (24%) and to undertake longer trips (24%). The majority of e-bikers use a helmet (60%). The answer to e-bike specific questions among age groups is shown in Supplementary materials.

Table 5 compares characteristics of e-bikers across four groups of substituted travel mode. Most of e-bikers in Antwerp substituted bicycle and private motorized vehicle trips, while in Zurich most e-bike mainly substituted public transport. Furthermore, e-bikers substituting public transport consider e-biking more dangerous than the substituted mode, while those substituting car or bicycle do not report large differences in terms of perceived safety when comparing e-bike with the substituted mode.

Table 6 compares transport-related indicators of e-bikers across four groups of substituted travel mode. E-bikers that substituted a main transport mode still reported significantly more frequent use of this particular transport mode than the other groups. Thus, respondents that substituted private motorized vehicle trips with e-bike trips reported more frequent private motorized vehicle trips than those that substituted public transport or bicycle trips (11.0 vs. 5.5 and 7.1 days per month); respondents that substituted public transport trips use it more frequently than former private motorized vehicle and bicycle users (12.2 vs. 2.8 vs. 6.5) and respondents that substituted non-electric bicycle use it more often than former private motorized vehicle and public transport users (12.3 vs. 7.0 vs. 5.2). Similar patterns were observed when looking at average number of trips per day but differences are not significant. Moreover, respondents that substituted car trips with e-bike trips walked significantly less often than the other two groups (12.7 vs. 19.7, 17.4 days per month). The data also suggest that e-bikers that substituted private motorized vehicle trips reported longer bicycle, e-bike and private motorized vehicle trips in terms of duration and distance. Daily average travel duration and distance by e-bike seem to be longer among e-bikers that substituted private motorized vehicle trips

Table 2
Travel behaviour indicators by bicycle user type.

	E-bikers		Cyclists		Non-cyclists		All		
Variable	Value (CI)	N	Value (CI)	N	Value (CI)	N	Value (CI)	N	P-value
Mode use frequency (in days per month, N = persons)									
Walk	16.3 (15.4; 17.3)	365	18.9 (18.7; 19.1)	7212	20.0 (19.6; 20.4)	1758	19.0 (18.8; 19.2)	9335	< 0.001
Bicycle	7.9 (6.9; 8.9)	365	14.0 (13.7; 14.2)	7212			11.1 (10.9; 11.3)	9335	< 0.001
E-bike	14.5 (13.5; 15.5)	365					0.6 (0.5; 0.6)	9335	
Public transport	7.7 (6.8; 8.7)	365	10.4 (10.1; 10.6)	7212	16.6 (16.1; 17.0)	1758	11.4 (11.2; 11.6)	9335	< 0.001
Private motorized vehicle	8.0 (7.2; 8.8)	365	7.3 (7.1; 7.5)	7212	8.6 (8.2; 9.1)	1758	7.6 (7.4; 7.8)	9335	< 0.001
Average number of trips per day									
Walk	0.4 (0.3; 0.6)	204	0.7 (0.6; 0.7)	3942	0.8 (0.7; 0.9)	809	0.7 (0.6; 0.7)	4955	< 0.001
Bicycle	0.3 (0.2; 0.4)	204	1.1 (1.1; 1.2)	3942			0.9 (0.9; 0.9)	4955	< 0.001
E-bike	0.8 (0.7; 1.0)	204					0.0 (0.0; 0.0)	4955	
Public transport	0.5 (0.4; 0.6)	204	0.7 (0.7; 0.8)	3942	1.3 (1.2; 1.3)	809	0.8 (0.8; 0.8)	4955	< 0.001
Private motorized vehicle	0.7 (0.6; 0.9)	204	0.6 (0.6; 0.7)	3942	0.7 (0.6; 0.8)	809	0.7 (0.6; 0.7)	4955	0.215
Average trip duration (in minutes, N = trips)									
Walk	21.5 (18.0; 25.0)	250	21.7 (20.9; 22.5)	6971	24.4 (23.0; 25.9)	1601	22.2 (21.5; 22.9)	8822	0.009
Bicycle	41.9 (34.2; 49.5)	221	25.6 (25.1; 26.1)	11,099			25.9 (25.4; 26.5)	11,320	< 0.001
E-bike	35.0 (31.7; 38.3)	463					35.0 (31.7; 38.3)	463	
Public transport	54.8 (47.3; 62.4)	294	50.0 (49.1; 50.9)	7503	51.0 (49.4; 52.5)	2262	50.3 (49.5; 51.1)	10,059	0.094
Private motorized vehicle	34.0 (29.4; 38.5)	430	35.1 (33.9; 36.3)	6161	38.7 (36.0; 41.3)	1358	35.6 (34.6; 36.7)	7949	0.043
Daily average travel duration from travel diary (in minutes, N = persons)									
Walk	9.8 (6.2; 13.4)	204	16.1 (14.9; 17.4)	3942	22.0 (19.3; 24.6)	809	16.8 (15.7; 17.9)	4955	< 0.001
Bicycle	13.4 (8.6; 18.2)	204	30.3 (28.8; 31.7)	3942			24.6 (23.4; 25.8)	4955	< 0.001
E-bike	32.2 (24.0; 40.4)	204					1.3 (0.9; 1.7)	4955	
Public transport	26.2 (19.0; 33.4)	204	38.0 (36.0; 40.0)	3942	65.8 (60.8; 70.8)	809	42.1 (40.3; 43.9)	4955	< 0.001
Private motorized vehicle	26.3 (18.8; 33.7)	204	23.5 (21.8; 25.2)	3942	28.0 (24.0; 32.0)	809	24.3 (22.8; 25.8)	4955	0.089
Daily average travel duration from GPAQ (in minutes, N = persons)									
Walk	16.0 (12.5; 19.4)	298	22.3 (21.4; 23.3)	5771	43.1 (39.7; 46.5)	1328	25.8 (24.8; 26.8)	7397	< 0.001
Bicycle	9.9 (7.4; 12.4)	298	21.6 (20.8; 22.5)	5771			17.3 (16.6; 18.0)	7397	< 0.001
E-bike	23.4 (19.8; 26.9)	298					0.9 (0.8; 1.1)	7397	
Average trip distance (in km, N = trips)									
Walk	1.2 (0.9; 1.5)	250	1.0 (1.0; 1.1)	6971	1.2 (1.1; 1.3)	1601	1.1 (1.0; 1.1)	8822	< 0.001
Bicycle	8.4 (7.2; 9.7)	221	4.8 (4.7; 4.8)	11,099			4.8 (4.7; 4.9)	11,320	< 0.001
E-bike	9.4 (8.6; 10.2)	463					9.4 (8.6; 10.2)	463	
Public transport	19.3 (15.9; 22.7)	294	18.3 (17.4; 19.1)	7503	11.8 (11.1; 12.5)	2262	16.8 (16.2; 17.5)	10,059	< 0.001
Private motorized vehicle	18.0 (13.2; 22.8)	430	21.2 (20.0; 22.4)	6161	20.2 (17.8; 22.6)	1358	20.8 (19.8; 21.9)	7949	0.352
Daily average travel distance (in km, N = persons)									
Walk	0.5 (0.3; 0.7)	204	0.7 (0.7; 0.8)	3942	1.0 (0.9; 1.2)	809	0.8 (0.7; 0.8)	4955	< 0.001
Bicycle	2.5 (1.5; 3.5)	204	5.3 (5.0; 5.5)	3942			4.3 (4.1; 4.5)	4955	< 0.001
E-bike	8.0 (6.2; 9.7)	204					0.3 (0.2; 0.4)	4955	
Public transport	9.5 (6.2; 12.8)	204	13.5 (12.4; 14.7)	3942	14.9 (13.3; 16.5)	809	13.6 (12.7; 14.5)	4955	0.117
Private motorized vehicle	11.8 (8.3; 15.3)	204	12.9 (11.7; 14.1)	3942	12.7 (10.5; 15.0)	809	12.8 (11.8; 13.9)	4955	0.914

N = sample size. CI = confidence interval. GPAQ = Global Physical Activity Questionnaire. P-value of the first three groups was calculated using ANOVA test.

and public transport trips. However, none of these findings regarding duration and distance are significant.

Regarding physical activity indicators, Table 7 shows that on average e-bikers that substituted bicycle trips lost around 200 MET minutes per week as a result of using an e-bike, while e-bikers replacing private motorized vehicle and public transport trips have a gain of around 550 and 800 MET minutes per week respectively. MET minutes per week of work-related activities were significantly higher among e-bikers that substituted bicycle trips than those that substituted public transport trips (2312 vs. 736 MET minutes). Moreover, e-bikers that substituted bicycle trips seemed to

Table 3
Physical activity indicators by bicycle user type.

	E-bikers		Cyclists		Non-cyclists		All		
Variable	Value (CI)	N	Value (CI)	N	Value (CI)	N	Value (CI)	N	P-value
Metabolic Equivalent of Task (MET) minutes per week by type of activity									
Work	1408 (1048; 1769)	298	852 (793; 911)	5771	973 (831; 1115)	1328	896 (841; 951)	7397	< 0.001
Travel	1736 (1559; 1912)	298	1656 (1610; 1702)	5771	1207 (1112; 1302)	1328	1578 (1538; 1619)	7397	< 0.001
Recreational	1319 (1160; 1477)	298	1577 (1524; 1631)	5771	1127 (1019; 1235)	1328	1486 (1440; 1533)	7397	< 0.001
Total	4463 (3999; 4926)	298	4085 (3978; 4191)	5771	3308 (3076; 3540)	1328	3961 (3866; 4056)	7397	< 0.001
MET minutes per week by active mode in travel-related activities									
Walk	447 (351; 542)	298	626 (599; 653)	5771	1207 (1112; 1302)	1328	723 (695; 751)	7397	< 0.001
Bicycle	471 (353; 590)	298	1030 (991; 1069)	5771			823 (791; 855)	7397	< 0.001
E-bike	817 (694; 941)	298					33 (27; 39)	7397	
Meeting WHO recommendations for physical activity (at least 600 MET minutes per week)									
No	3% (1%; 5%)	8	4% (4%; 5%)	237	14% (13%; 16%)	192	6% (5%; 6%)	437	< 0.001
Yes	97% (96%; 99%)	290	96% (95%; 96%)	5534	86% (84%; 87%)	1136	94% (94%; 95%)	6960	
Total	100%	298	100%	5771	100%	1328	100%	7397	
Days on a typical week with 30 min or more of physical activity (single-item physical activity measure)									
(Mean)	4.2 (3.9; 4.4)	351	4.0 (3.9; 4.0)	6975	3.2 (3.1; 3.3)	1685	3.8 (3.8; 3.9)	9011	< 0.001

N = sample size. CI = confidence interval. WHO = World Health Organization. P-value of the first three groups was calculated using ANOVA test for continuous variables and Chi-square test for categorical and binomial variables.

Table 4
E-bike specific questions.

Variable	E-bikers	
	Value (CI)	N
Transport mode substituted in e-bike trips		
Private motorized vehicle	25% (20%; 31%)	93
Public transport	15% (9%; 20%)	53
Bicycle	23% (18%; 28%)	83
Other	1% (0%; 7%)	5
None	4% (0%; 9%)	14
Combination of modes	32% (27%; 38%)	117
Total	100%	365
Main motivation to start riding an e-bike		
Less effort (than cycling or walking)	26% (21%; 31%)	95
Faster (than traditional bike, public transport or car)	24% (19%; 30%)	89
Need or desire to travel longer distances	24% (19%; 29%)	87
Environmental considerations	5% (0%; 10%)	18
Health considerations	10% (5%; 16%)	38
Other	10% (5%; 16%)	38
Total	100%	365
Helmet when e-biking		
No	40% (35%; 45%)	147
Yes	60% (55%; 65%)	218
Total	100%	365

N = sample size. CI = confidence interval.

report overall higher levels of physical activity in terms of MET minutes and single-item physical activity measure, but differences are not significant.

4. Discussion

This study has found that physical activity from travel-related activities is similar for e-bikers and cyclists, as measured by MET minutes per week based on the GPAQ and on the single-item physical activity measure. Moreover, overall physical activity among both groups was also comparable. These findings counter the often-raised concern that e-biking may result in a substantial reduction of physically activity for traveling due to the electric assist of e-bikes, which reduces the required physical effort. As this study shows, average trip distance of e-bike and bicycle trips among e-bikers is significantly higher than bicycle trips among cyclists. Equally, e-bikers' daily travel distance by e-bike was also significantly longer than daily cycling distance in cyclists (see Table 2), which confirms reviewed literature. This suggests that e-bikers may compensate, at least in part, the lower effort per kilometre of e-biking by traveling longer distances. Whether this pattern is caused by subjects switching to e-bikes who are constraint to longer trips, i.e. longer commute distances, or whether subjects who switched to e-biking changed their travel habits towards longer trips because of the expanded range cannot be determined conclusively with the available data. Similarly, it remains unclear why conventional bike trips are longer in e-bikers.

One may suspect that e-bike trips are longer because of a higher proportion of recreational trips, compared to bicycle trips. However, the share of recreational trips is lower among e-bikers than among cyclists (results not shown), and recreational physical activity reported in GPAQ was also lower among e-bikers than among cyclists (see Table 3).

Against general concern that e-bikes mainly replace more intense, and therefore healthier travel by conventional bicycle, the presented data showed a fairly even split of e-bikers substituting car, public transport and cycling trips, which is consistent with reviewed literature. This implies that e-biking is not only a viable option for healthy transport, but also broadens sustainable transport options offering a competitive alternative for urban motorized modes. It should be noted though that the substituted mode continues to play a substantial role in e-bikers' travel patterns (see Table 6). In other words, e-bikes serve as partial substitutes of subjects' main travel modes, but they hardly replace these completely.

Assessing the net effects of switching to e-biking by mode, this study found that on average the substitution of cycling lead to a loss of around 200 MET minutes per week, while the substitution of private motorized vehicle or public transport trips resulted in a gain of around 550 to 800 MET minutes per week, respectively (see Table 7). This finding confirms that e-

Table 5
Characteristics of e-bikers by travel mode substituted with e-bike.

Variable	Bicycle		Public transport		Private motorized vehicle		Other or multiple mode		P-value
	Value (CI)	N	Value (CI)	N	Value (CI)	N	Value (CI)	N	
City									
Antwerp	34% (25%; 44%)	38	7% (0%; 18%)	8	38% (29%; 48%)	42	21% (12%; 32%)	24	<0.001
Barcelona	15% (0%; 38%)	3	35% (15%; 58%)	7	25% (5%; 48%)	5	25% (5%; 48%)	5	
London	60% (40%; 100%)	3					40% (20%; 91%)	2	
Örebro	22% (41%; 85%)	4	6% (6%; 6%)	1	17% (0%; 44%)	3	56% (0%; 44%)	10	
Rome	5% (0%; 19%)	3	13% (2%; 27%)	8	49% (38%; 63%)	31	33% (22%; 47%)	21	
Vienna	30% (44%; 74%)	12	12% (18%; 48%)	5	2% (2%; 2%)	1	55% (0%; 30%)	22	
Zurich	19% (9%; 29%)	20	22% (13%; 32%)	24	10% (1%; 20%)	11	49% (39%; 58%)	52	
Sex									
Male	21% (16%; 27%)	39	15% (11%; 21%)	28	26% (20%; 32%)	48	39% (32%; 46%)	72	0.845
Female	25% (19%; 32%)	44	14% (10%; 20%)	25	25% (19%; 32%)	45	36% (29%; 43%)	64	
Age									
(mean)	48.4 (45.7; 51.0)	83	47.4 (44.9; 49.9)	53	47.6 (45.6; 49.7)	93	48.7 (46.7; 50.6)	136	0.855
Level of education									
University or similar	21% (16%; 27%)	45	17% (12%; 22%)	35	27% (21%; 33%)	57	35% (29%; 42%)	75	0.577
Lower degree	22% (14%; 31%)	20	11% (6%; 19%)	10	27% (19%; 37%)	25	41% (31%; 51%)	38	
HFCE-adjusted income (in thousand EUR per year)									
(mean)	76.6 (64.5; 88.6)	83	78.1 (62.5; 93.7)	53	72.0 (60.4; 83.5)	93	77.5 (68.2; 86.9)	136	0.879
Car/van access									
Always	19% (13%; 26%)	48	13% (6%; 19%)	31	31% (25%; 38%)	77	37% (30%; 44%)	91	0.006
Sometimes	30% (20%; 42%)	27	16% (6%; 27%)	14	15% (4%; 26%)	13	39% (29%; 51%)	35	
Never	28% (10%; 47%)	8	28% (10%; 47%)	8	10% (0%; 30%)	3	34% (17%; 54%)	10	
Body Mass Index									
(mean)	24.6 (23.8; 25.4)	66	24.6 (23.4; 25.8)	45	25.0 (24.2; 25.9)	83	24.9 (24.3; 25.6)	112	0.830
Perceived safety of e-bike compared to substituted transport mode (values range from 1 = much less safe to 10 = much safer)									
(Mean)	5.3 (5.0; 5.7)	83	3.8 (3.1; 4.6)	53	4.9 (4.4; 5.4)	93	4.9 (4.5; 5.3)	136	0.002

N = sample size. CI = confidence interval. HFCE = national price level index for household final consumption expenditure. Row-wise percentages. P-value of the four groups was calculated using ANOVA test for continuous variables and Chi-square test for categorical and binomial variables.

Table 6
Transport-related indicators by travel mode substituted with e-bike.

	Transport mode substituted with e-bike								
	Bicycle		Public transport		Private motorized vehicle		Other or multiple mode		
Variable	Value (CI)	N	Value (CI)	N	Value (CI)	N	Value (CI)	N	P-value
Mode use frequency (in days per month, N = persons)									
Walk	17.4 (15.4; 19.3)	83	19.7 (17.7; 21.8)	53	12.7 (10.5; 14.9)	93	16.9 (15.4; 18.4)	136	<0.001
Bicycle	12.3 (10.0; 14.7)	83	5.2 (2.9; 7.6)	53	7.0 (5.1; 8.9)	93	6.8 (5.3; 8.3)	136	<0.001
E-bike	14.6 (12.5; 16.7)	83	16.3 (13.9; 18.7)	53	17.7 (15.9; 19.4)	93	11.5 (9.9; 13.2)	136	<0.001
Public transport	6.5 (4.6; 8.4)	83	12.2 (9.6; 14.8)	53	2.8 (1.7; 3.9)	93	10.1 (8.4; 11.8)	136	<0.001
Private motorized vehicle	7.1 (5.5; 8.6)	83	5.5 (3.8; 7.2)	53	11.0 (9.3; 12.7)	93	7.6 (6.2; 9.0)	136	<0.001
Average number of trips per day									
Walk	0.3 (0.1; 0.5)	38	0.9 (0.4; 1.5)	36	0.2 (0.1; 0.3)	57	0.5 (0.3; 0.6)	73	0.001
Bicycle	0.5 (0.2; 0.9)	38	0.2 (−0.0; 0.4)	36	0.1 (0.0; 0.2)	57	0.4 (0.2; 0.6)	73	0.044
E-bike	0.7 (0.4; 1.0)	38	1.1 (0.7; 1.5)	36	1.1 (0.9; 1.4)	57	0.5 (0.3; 0.8)	73	0.002
Public transport	0.5 (0.2; 0.8)	38	0.6 (0.4; 0.9)	36	0.2 (0.1; 0.4)	57	0.6 (0.4; 0.8)	73	0.043
Private motorized vehicle	0.8 (0.4; 1.1)	38	0.5 (0.1; 0.9)	36	0.7 (0.5; 0.9)	57	0.9 (0.5; 1.2)	73	0.553
Average trip duration (in minutes, N = trips)									
Walk	15.8 (12.2; 19.3)	50	22.4 (14.6; 30.1)	68	20.8 (15.1; 26.4)	39	24.3 (17.2; 31.4)	93	0.388
Bicycle	35.1 (25.1; 45.2)	86	32.5 (18.9; 46.0)	18	52.0 (35.5; 68.6)	25	47.2 (32.1; 62.3)	92	0.361
E-bike	26.2 (21.8; 30.5)	99	33.7 (22.7; 44.7)	120	41.2 (38.1; 44.4)	127	37.1 (32.9; 41.2)	117	0.016
Public transport	55.4 (42.2; 68.5)	50	52.5 (48.1; 56.8)	86	44.8 (37.5; 52.1)	40	59.8 (42.1; 77.4)	118	0.636
Private motorized vehicle	29.0 (23.9; 34.2)	89	33.0 (23.4; 42.6)	75	41.8 (29.7; 53.9)	128	30.4 (24.2; 36.6)	138	0.162
Daily average travel duration from travel diary (in minutes, N = persons)									
Walk	4.4 (1.1; 7.6)	38	20.8 (5.4; 36.1)	36	4.8 (1.0; 8.7)	57	11.1 (5.3; 16.9)	73	0.016
Bicycle	20.8 (8.9; 32.7)	38	6.1 (−0.9; 13.2)	36	7.9 (2.0; 13.7)	57	17.5 (6.9; 28.1)	73	0.125
E-bike	17.9 (8.1; 27.7)	38	48.8 (12.0; 85.6)	36	48.3 (35.6; 61.1)	57	18.8 (10.1; 27.5)	73	0.004
Public transport	27.4 (7.2; 47.6)	38	33.6 (20.8; 46.5)	36	8.8 (1.9; 15.7)	57	35.5 (20.4; 50.6)	73	0.024
Private motorized vehicle	28.9 (11.8; 46.0)	38	26.8 (−0.6; 54.2)	36	23.0 (13.8; 32.1)	57	27.2 (14.9; 39.5)	73	0.956
Daily average travel duration from GPAQ (in minutes, N = persons)									
Walk	17.6 (7.9; 27.3)	64	22.7 (9.4; 36.0)	45	8.0 (4.8; 11.1)	82	18.2 (13.6; 22.9)	107	0.030
Bicycle	17.3 (10.4; 24.3)	64	5.6 (1.5; 9.8)	45	8.6 (3.5; 13.6)	82	8.3 (4.8; 11.8)	107	0.017
E-bike	16.0 (10.3; 21.7)	64	31.7 (22.1; 41.3)	45	31.5 (22.8; 40.1)	82	18.0 (13.2; 22.9)	107	0.001
Average trip distance (in km, N = trips)									
Walk	0.6 (0.5; 0.8)	50	1.3 (0.7; 1.9)	68	1.1 (0.1; 2.1)	39	1.4 (0.9; 1.9)	93	0.305
Bicycle	6.8 (5.1; 8.4)	86	9.9 (3.7; 16.2)	18	12.1 (6.8; 17.3)	25	8.7 (6.9; 10.5)	92	0.070
E-bike	7.5 (5.4; 9.7)	99	8.7 (6.9; 10.5)	120	11.3 (10.0; 12.6)	127	9.8 (8.5; 11.1)	117	0.012
Public transport	19.3 (6.0; 32.5)	50	24.5 (19.0; 30.1)	86	10.4 (5.3; 15.4)	40	18.6 (13.9; 23.4)	118	0.095
Private motorized vehicle	12.7 (10.0; 15.4)	89	14.2 (9.3; 19.1)	75	28.2 (12.8; 43.6)	128	14.1 (11.0; 17.2)	138	0.058
Daily average travel distance (in km, N = persons)									
Walk	0.2 (0.0; 0.3)	38	0.9 (0.5; 1.4)	36	0.3 (−0.1; 0.6)	57	0.7 (0.3; 1.2)	73	0.055
Bicycle	3.4 (1.1; 5.6)	38	1.7 (−0.8; 4.2)	36	2.1 (0.2; 3.9)	57	2.7 (0.9; 4.5)	73	0.748
E-bike	4.9 (1.8; 8.1)	38	8.2 (5.0; 11.3)	36	13.9 (9.4; 18.3)	57	4.8 (2.5; 7.2)	73	<0.001
Public transport	9.4 (−0.3; 19.0)	38	16.7 (8.4; 25.0)	36	2.0 (0.2; 3.8)	57	11.9 (5.5; 18.2)	73	0.019
Private motorized vehicle	10.5 (4.7; 16.4)	38	6.9 (2.3; 11.5)	36	15.9 (6.3; 25.6)	57	11.6 (6.6; 16.7)	73	0.396

N = sample size. CI = confidence interval. GPAQ = Global Physical Activity Questionnaire. P-value of the four groups was calculated using ANOVA test variables.

Table 7
Physical activity indicators by travel mode substituted with e-bike.

	Transport mode substituted with e-bike								
	Bicycle		Public transport		Private motorized vehicle		Other or multiple mode		
Variable	Value (CI)	N	Value (CI)	N	Value (CI)	N	Value (CI)	N	P-value
Metabolic Equivalent of Task (MET) minutes per week by type of activity									
Work	2312 (1513; 3111)	64	736 (197; 1276)	45	1107 (470; 1743)	82	1381 (680; 2083)	107	0.045
Travel	1877 (1448; 2307)	64	2013 (1428; 2598)	45	1732 (1396; 2069)	82	1536 (1303; 1770)	107	0.289
Recreational	1403 (1054; 1752)	64	1336 (864; 1807)	45	1365 (1008; 1722)	82	1226 (1015; 1437)	107	0.850
Total	5592 (4512; 6673)	64	4085 (3076; 5095)	45	4204 (3363; 5045)	82	4144 (3324; 4964)	107	0.096
MET minutes per week by active mode in travel-related activities									
Walk	493 (222; 764)	64	635 (262; 1009)	45	223 (136; 311)	82	511 (381; 640)	107	0.030
Bicycle	825 (494; 1155)	64	268 (70; 466)	45	408 (167; 649)	82	394 (227; 562)	107	0.017
E-bike	560 (360; 759)	64	1110 (774; 1445)	45	1101 (798; 1404)	82	631 (462; 801)	107	0.001
Meeting WHO recommendations for physical activity (at least 600 MET minutes per week)									
No	2% (2%; 2%)	1	2% (2%; 2%)	1	5% (1%; 9%)	4	2% (0%; 4%)	2	0.546
Yes	98% (100%; 100%)	63	98% (100%; 100%)	44	95% (91%; 99%)	78	98% (96%; 100%)	105	
Total	100%	64	100%	45	100%	82	100%	107	
Days on a typical week with 30 min or more of physical activity (single-item physical activity measure)									
(mean)	4.7 (4.2; 5.1)	80	4.2 (3.7; 4.7)	51	4.2 (3.8; 4.6)	89	3.8 (3.5; 4.2)	131	0.027
MET minutes per week before using e-bike									
Travel	2079 (1630; 2527)	64	1192 (674; 1710)	45	1182 (926; 1438)	82			0.001
MET minutes change after using e-bike									
Travel	−202 (−273; −130)	64	821 (573; 1070)	45	550 (399; 702)	82			<0.001

N = sample size. CI = confidence interval. WHO = World Health Organization. P-value of the four groups was calculated using ANOVA test for continuous variables and Chi-square test for categorical and binomial variables.

biking offers considerable potential for health benefits, especially among non-cyclists.

Of particular interest from a health perspective would be to understand how such compensatory behaviour plays out in the long run, leading elderly people to use e-bikes more regularly and until older ages, than they could physically handle to ride a conventional bicycle. As inactivity affects chronic disease risks, elderly, increasingly sedentary subjects benefit even more from regular activity as part of their day-to-day life than younger subjects (Taylor et al., 2004). The e-bike specific questions of Table 4 by age groups in the Supplementary materials did not show substantial differences among groups. A proper longitudinal analysis would be required to address this question, but the significantly higher age of e-bikers in this study is consistent with previous research suggesting higher e-bike use in elderly (Haustein and Møller, 2016). Comprehensive health impact assessment should then, however, also take into account increased injury risks that may be associated with e-biking in elderly.

Injury risks associated with either mode are outside the scope of this paper. Assessment of e-bikes safety was not possible in PASTA because too few incidents with e-bikes were registered during the survey. E-bikers reported perceived safety of e-biking relative to substituted mode, indicating that public transport is safer, but compared to other modes, e-biking is perceived equally safe. This may come somewhat as a surprise relative to bicycling, as current discourse often describes e-bikes as more dangerous due to higher speed and weight. Whether e-bikers underestimate increased risks of e-bikes, or whether to what extent they compensate these with more prudent riding behaviour is subject to further research. A study in the Netherlands found that e-biking has been associated with higher likelihood of having a traffic crash compared to conventional cycling, while severity of injuries seems to be similar (Schepers et al., 2014). A later analysis in the same country and by the same author found that e-bike and conventional bicycles users have similar likelihood of being treated in emergency departments of hospitals due to traffic crashes (Schepers, 2018).

E-bikers had significantly higher BMI than cyclists, and somewhat higher than non-cyclists. However, it should be remarked that average BMI values across the three groups can be considered as normal, i.e. as neither under nor overweight (WHO-Europe). In the context of this cross-sectional analysis, this result should be interpreted as a result of self-selection. Thus, the higher BMI may reflect the appeal of electric assist bikes for persons with high BMI that aim to overcome the physical burden of conventional cycling (in particular for heavier subjects), rather than a physiological effect of lower physical activity levels of e-biking. Evidence for physiological causality of physical activity reducing BMI is limited, counter to common belief. However, Dons and colleagues (Dons et al., 2018) were able to observe significant effects of changes in cycling on BMI, in PASTA subjects observed for more than one year. Effects from their longitudinal analysis however were smaller than those of their cross-sectional analysis, which also indicates some degree of self-selection.

This study is a unique case of simultaneous assessment of travel and physical activity indicators between e-bikers, cyclists, and non-cyclists, as well as across e-bikers grouped by the main mode they substituted with e-bike, and as such provides unique perspectives on e-biking in Europe. The strength of this analysis is its large sample size and geographic range, resulting in a fairly large sample of European e-bikers, as well as the rich data combining travel and physical activity indicators.

Nevertheless, some limitations of this study need to be acknowledged.

The seven European cities analysed in the PASTA data are different in terms of bicycle use and infrastructure (Raser et al., 2018), and as such capture some of the European diversity quite well. Nevertheless, it should be remarked that aggregated mean values of the seven European cities are not necessarily representative of the whole continent. The differences across the seven cities and their different representation in the groups of users in this study (e-bikers vs. cyclists) limits the generalizability of the results, in particular as only 1% of the e-bikers in the data were from London and 5% from Barcelona and Örebro, while Antwerp and Zurich are represented with 31% and 29%, respectively. The high level of e-bike use in Antwerp may be due to the high level of cycling across all ages and forefront of cycling development in Netherlands. In Zurich, hilliness, wealthiness and some established cycling culture in Switzerland might explain the high level of e-bike use. Unfortunately, the limited sample size of e-bike users in the PASTA data did not allow for a local assessment at city level or comparisons between cities. Nevertheless, it consists one of the richest data sets on e-bikers published to date.

Data were collected through an on-line survey using opportunistic sampling strategies. This approach may have biased the overall sample, in particular towards the young and well educated. Further, cyclists were purposefully oversampled. Along with the obvious limitations of opportunistic sampling and exclusively using an online survey platform which excluded people with no internet access from the study, the main concern for bias in the e-bike sample is under-representation of elderly e-bike users. Thus, the analysis of older age groups, of particular interest in health promotion, as pointed out above, was hampered in the PASTA sample (30% above 50 years old and 10% above 60 years old), which limited the generalizability of our findings to the elderly. However, it is not obvious what factor would affect recruitment of cyclists vs. e-bikers, or e-bikers shifting from different modes differentially. As such we do not expect that the sampling strategy had a major influence on the presented results.

Although the PASTA survey was longitudinal, the analysis of the current study is cross-sectional in nature, i.e. comparing travel behaviour across three cyclist groups consisting of different subjects (e-bikers, cyclists, non-cyclists). Observed difference may not solely be attributed to differences in cycling category, but also to underlying characteristics of subjects. Also, the analysis of mode substitution by e-bike is based on self-reported information and is not truly longitudinal in design. Ideally, to evaluate the impact of the uptake of e-bike on physical activity, physical activity levels should be measured in the same individuals before and after taking up e-biking. Unfortunately, the PASTA survey only observed a single person starting to e-bike during the survey period (i.e. answering that they started using e-bike less than three months ago in an intermediary follow-up questionnaire).

Travel duration and distance may be affected by inaccuracies. Average daily durations reported in the GPAQ questionnaire were lower for e-biking and cycling, but higher for walking, as compared to the travel diary. This pattern was consistent across all three groups. Furthermore, daily duration was estimated comparing self-reported end and start time of trips and trips were assigned to a transport mode according to the main transport mode. Beyond the likely inaccuracies of self-reported data compared to automatic track devices, multi-modal trips overestimate the travel duration of the main mode, since the total duration of all involved modes are assigned to the main one. Travel distance was estimated based on the same main-mode approach. Furthermore, respondents did not provide information on the route, thus the fastest route provided by Google Maps for the trip from origin to destination was assumed. Moreover, round trips (trips with the same start and end point were removed from the data set because they wrongly lead to zero kilometres. Therefore, trip distance might be underestimated. Further uncertainty is embedded in our assumptions for intensity of physical activity, in particular with MET values for e-biking, driving and public transport.

Future research should achieve a larger sample size of e-bikers, which enables stronger statistical power for the assessment of effects of modal switch to e-bike, as well as for specific user groups such as elderly and specific aspects such as safety. However, to conduct such studies prospectively remains extremely challenging and would require targeted recruitment strategies focusing on potential e-bikers to achieve sufficient sample size. Conducted retrospectively, i.e. asking e-bike users about the past, similar to the approach in PASTA, is more feasible, but prone to misclassification due to recall bias. Nonetheless, findings from this analysis may prove helpful to tailor future research efforts on e-biking and inform policy related to e-bike promotion. Furthermore, future publications may explore determinants of mobility behaviour of e-bikers, cyclist and non-cyclists. For instance, slope of routes, distances from home to work, weather conditions, local infrastructure and regulation might influence e-bike use.

5. Conclusion

In conclusion, this analysis supports the notion to accept, or even promote, e-bikes as a healthy and sustainable transport option based on e-bikers travel behaviour and self-reported mode substitution. Planers should be aware that e-bikers travel longer distances than cyclists. Thus, e-bikes might be used for longer commuting trips than non-electric bicycles. To accommodate (or promote) this new demand and to avoid conflicts with other road users in urban areas, cycling infrastructure should be expanded and may need to be adapted to accommodate higher speeds and address safety needs. The health benefits in terms of physical activity of using e-bikes, particularly when replacing car trips, should be factored in when considering subsidizing e-biking.

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Author contribution statement

The authors confirm contribution to the paper as follows:

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- Data collection: Alberto Castro, Mailin Gaupp-Berhausen, Evi Dons, Arnout Standaert, Michelle Laeremans, Anna Clark, Esther Anaya, Tom Cole-Hunter, Ione Avila-Palencia, David Rojas-Rueda, Mark Nieuwenhuijsen, Regine Gerike, Luc Int Panis, Audrey de Nazelle, Christian Brand, Elisabeth Raser, Sonja Kahlmeier, Thomas Götschi
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- All authors reviewed the results and approved the final version of the manuscript

Appendix A. Supplementary data

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